POWER HOUSE DESIGN

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PREFACE TO SECOND EDITION

THE widespread demand for a second edition of "Power House Design" has been very gratifying to the Author, and he has felt encouraged by the distribution of the first edition throughout the British Dominions overseas, in the country of our great Ally the United States of America, on the Continent of Europe, and in far-off Japan.

In compiling the second edition the Author has been greatly assisted by Mr. R. T. G. French, B.A., without whose assistance, indeed, the issue would have been greatly delayed, and the (as it is hoped) more methodical sequence of the subject matter would probably have not been arranged.

The Author has experienced much difficulty in referring to costs throughout the new edition owing to the varying and increased prices brought about by the late War. He has therefore felt compelled to base his references on pre-war figures, leaving those who do him the honour of reading this book to adopt such a multiplier as the time and circumstances of the country to which it is sought to apply the prices, may demand.

With regard to technical matters, there have been many noteworthy developments in all branches of power house design since the original edition was written in 1911. It has therefore been necessary entirely to recast some of the chapters, and every effort has been made throughout the second edition to include the most up-to-date particulars of machinery and plant required for modern power houses.

The Author's indebtedness is due to Messrs. Merz & McLellan, Sir Dugald Clerk, K.B.E., F.R.S., Messrs. Preece, Cardew & Rider, Mr. W. L. Shand, the General Electric Company of America, the British Engineering Standards Association, the Publishers of "Railway News" and "The Railway Gazette," and to the Institutions, Authors of Papers and Manufacturers referred to in the text, as well to those already mentioned in the first Preface, who so generously and whole-heartedly placed their information and knowledge at his disposal.

JOHN SNELL.

May, 1921.

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PREFACE TO FIRST EDITION

THE Author ventures to hope that the principles and information given in this book, together with the typical examples of modern power houses shown, will be of some use to his engineering brethren, whether civil, mechanical, electrical, or mining engineers.

He does not claim to have introduced any noticeable originality, but rather to have drawn upon his own experience, and to have collected and classified the experience of other and more eminent engineers. By condensing this information in a practical form in one book, an endeavour has been made to give all the requisite practical information on power house design, and thus to save the loss of time which results from searching through numbers of text-books, proceedings of Institutions, and the admirable descriptions of power houses in the Technical Press. The information selected has been carefully sifted out by the Author's experience gained in various power stations over a period of more than twenty years, and especial care has been taken to avoid errors and to preserve exactitude.

The Author desires to express his indebtedness to Messrs. H. W. Kolle; J. H. Rider; C. Stanley Peache; Leonard Andrews; S. S. Moore Ede; J. Shepherd; B. M. Jenkin; Belliss and Morcom; Browett, Lindley & Co.; British Westinghouse Electric and Manufacturing Co.; Galloways, Ltd.; Dick, Kerr & Co.; E. Green & Sons; Herbert Morris & Bastert; Balcke & Co.; Böving & Co.; British Thomson-Houston Co.; The Inter-

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JOHN F. C. SNELL.

July, 1911.

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INTRODUCTION

Power houses for the generation of electrical energy are now indispensable for industrial and civic requirements. The Author will endeavour in this work to give reliable and up-to-date information on the design and equipment of stations required for the supply of power, light, and other purposes within cities or over more scattered and wider areas, as for power distribution to mines, groups of collieries and various works, for suburban or other railway services, tramways and light railways; and also of smaller independent power houses and sub-stations for large factories.

In order to cover adequately so wide a survey it will be necessary to enunciate certain principles and to establish certain data for the guidance of the designer, since power houses with steam, oil, and gas prime movers will be dealt with, and also hydro-electric plants. It is neither proposed to trench on the province of other text-books dealing with the fundamental principles of thermodynamics, electrotechnics, or hydraulics, nor to deal with the design of the prime movers and electrical machines; but rather to assume a certain knowledge of these, and at once to proceed to their adaptation and to the elements of successful power house design and operation.

The design of all power houses must depend on several conditions, such as—

(*a*) The nature of the service for which energy is to be supplied.

(*b*) Environment, or the position of the site and accessibility to water and fuel; length of transmission; climatic conditions, and geographical position.

(*c*) Commercial requirements from the undertaking.

(*d*) Probabilities of future development.

No engineer would, for example, lay down a low-pressure

direct-current plant for the supply of a large area having a radius of several miles. Neither would he install a water-power plant, involving an expensive embankment and pipe line and heavy capital charges, if lower annual costs either in the immediate or in the ultimate services required could be secured with, say, steam-turbine plant in spite of the dependence of the latter upon costly fuel in the particular case. Nor would a 3-phase high-pressure system be adopted in a compact area which could be more economically dealt with by a simple direct-current system, unless there were special reasons to the contrary (as in the case of mines where alternating-current motors may be preferable, or where a gradually extending radius of supply had to be considered). These and many other points have to be taken into account when considering the design and types of plant to be adopted for any particular duty.

It is because the future success of industrial undertakings, both at home and abroad, depends so much on the skilful judgment exercised in the selection of the fundamental system of supply, i.e. on the special adaptability of the system adopted to the requirements of the district, factory, mine, or whatever it may be, that a book of this nature may prove of use to engineers, especially to those who in some out-of-the-way corner of the globe may be called upon to construct a power house without an opportunity of obtaining advice from some expert in this branch of engineering, and also to civil engineers in their ever-increasing reliance upon electrical auxiliaries.

The essential problem is to provide a power house and electrical system at a minimum capital cost consistent with good and durable engineering work, together with subsequent minimum resultant working costs.

The design of the power house cannot be considered apart from the whole undertaking, and the designer has to bear in mind the transmission lines or feeders, as well as the nature of the load and the load factor. It would be of little use designing the most economical power house, and then to neutralize the economy so gained by an undue expenditure on cables and other apparatus.

Wherever the density of industries, population, and transport

render it economically feasible, modern developments require the establishment of large 3-phase power stations, with large units of plant, for supplying electrical energy over wide areas in order to secure better station load factors and other economies. Nevertheless, there must always remain isolated towns, factories or groups of factories, mines, etc., especially in new countries, where smaller power houses are required. It is to give useful information for such varying classes of requirements that these notes have been prepared. Moreover, they are intended to be generally applicable, not only to Great Britain but also to the Dominions overseas and to other countries.

The costs quoted throughout this book are *pre-war* figures unless definitely specified to the contrary. In making estimates therefrom, a correction must accordingly be made to adjust the costs to present-day figures; for the United Kingdom these range from 2 to 2·5 times pre-war costs. It is to be hoped that the crest of prices has already been reached and that more settled industrial conditions generally, coupled with increased production and a return of better transport facilities, will bring about a reduction from the present abnormal figures.

CHAPTER I

SYSTEMS

THE more usual or recommended voltages and frequencies in Great Britain and America are given in Tables Nos. I. and II.

TABLE I.

VOLTAGES AND FREQUENCIES: GENERATION AND TRANSMISSION.

System.	American practice.		British practice.	
	Voltage.	Frequency.	Voltage.[1]	Frequency.[2]
Direct current—				
Low pressure . .	250	—	242	—
	550-600	—	484	—
High pressure [3]. .	not fixed	—	not fixed	—
Alternating current—				
Single-phase . .	—	15 or 25	6,600	25 or 50
Three-phase . .	2,200	25 or 60	3,300	25 or 50
	—	—	6,600	do.
	2,200 *	25 or 60	11,000 *	do.
	6,600 *	do.	33,000 *	do.
	11,000 *	do.	66,000 *	do.
	22,000 *	do.	etc.	
	33,000 *	do.		
	44,000 *	do.		
	66,000 *	do.		
	88,000 *	do.		
	and higher			

NOTES.—(1) Recommended in British Standard Specification No. 77/1921 for new systems.

(2) While a standard of 50 cycles per second is recommended, exception is made in British practice where the circumstances demand a lower frequency, in which case a standard of 25 cycles per second is adopted. There [illegible] where a frequency of 40 cycles per second has been widely developed.

(3) The maximum pressure adopted on the Thury system has been 7200 volts per generator on the Moutiers-Lyon transmission scheme, which has a total line pressure of 57,600 volts.

* Transmission voltages. Voltages above 11,000 are not yet in use in Great Britain to any extent.

Thus, in American practice, with a terminal voltage of 2200 in alternating current generation, there can be a step-down

transformer ratio either of one-tenth or one-twentieth for distribution, and a step-up ratio for transmission in direct multiples of the generator terminal voltage, viz. 3, 5, 10, 15, 20, 30, 40, and higher. A range of terminal voltage from standard voltage at no-load to 10 per cent. over the standard figure is recommended to cover the drop in the transmission circuit.

In British practice the terminal voltage is usually 6600 with step-down ratios of one-thirtieth, and occasional cases of step-up ratios of 66 to 110, 220 or 330.

Each system has its uses, and it would be beyond the scope of this book to enter into more than a general comparison of them. It is impossible to lay down specific rules, as each system must be considered in relation to the general service required, length of transmission, average load factor, source of power, and other factors.

TABLE II.

VOLTAGES AND FREQUENCIES: CONSUMERS' OR DELIVERED PRESSURES.

System.	American practice.		British practice.	
	Voltage.	Frequency.	Voltage.[1]	Frequency.
Direct current	110	—	220	—
	220	—	440	—
Alternating current	110	25 or 60	240/416	25 or 50
	220	do.	3000	do.
	2000	do.	6000	do.
	6000	do.	10,000	do.
	etc.			

NOTE.—(1) Recommended in British Standard Specification No. 77/1921 for new systems.

Two-phase systems are little used, and do not compare favourably in economy with 3-phase systems; they are therefore excluded from consideration.

In the case of pressures higher than 11,000 volts, it is customary and advisable (except in special cases of direct current as in the Thury system) for the power house generators to work at 6600 volts or smaller pressures, and to step up this pressure to

the higher line-pressure; otherwise the design of the machine, voltage per slot, etc., lead to increased cost and diminished safety as compared with a lower pressure machine in conjunction with an oil-immersed step-up transformer.

Recommended Systems to be Chosen.—In the Author's opinion 6600 volts is a reasonable maximum which he would wish to see universally standardized for power house generators. There would then be only four standard pressures required (excepting the special case of high-pressure direct-current), viz.:—

(*a*)	Three-phase	25 ∽ 6600 volts.
(*b*)	Three-phase	50 ∽ ditto (60 ∽ in America).
(*c*)	Single-phase	25 ∽ ditto.
(*d*)	Direct-current	484 volts.

As stated above, the fundamental system must be chosen to suit each particular district or local requirement, so long as a standardized pressure and frequency are adopted.

The purposes for which power houses are required and the most suitable systems in each case may be broadly classified as under:—

1. **Railways.**—Either single-phase overhead line construction at high pressure, the present practice ranging from 3000 volts to 11,000 volts, or direct-current third rail at from 600 to 1800 volts. In some American cases the distributing pressure is 1200 volts.

Both of these transmission systems may, and probably would, be independent of the power house conditions. In the former, the system itself would fix the frequency, whereas the pressure at the generator terminals could be independently fixed; and in the latter, the generators would almost certainly supply 3-phase 50 ∽ current to local rotary sub-stations. A load factor of 40 per cent. may be taken as a fair average for railway work, but each case will, of course, have to be worked out in detail.

2. **Power Supply over Large Areas.**—3-phase 50 ∽. In such a case the power house voltage would be fixed at 6600, stepping up where necessary for long transmission lines. An average load factor of 35 per cent. may generally be counted upon.

3. **General Supply to Large Cities.**—A 3-phase 50 ∽ system supplying rotary sub-stations for direct-current distribution, or

a 3-phase 4-wire low-pressure distribution system through step-down transformers. Including the requirements of local tramways and street railways, load factors of about 30 per cent. may be expected.

4. **Smaller Towns.**—Where a 3-phase system is not warranted by the radius of supply within any town or by the probable future requirements, then the simple direct-current system at 440 volts may be adopted. The economical radius of supply for such a direct-current system is about $1\frac{1}{4}$ miles from the power house. Without tramways supply and in a non-industrial district, an average load factor of about 15 per cent. is usual.

In such cases a benefit can be obtained from storage, and the installation of a suitable battery to carry the load during the night and at week ends and for a part of each day during the summer will be economical.

5. **Collieries and Mines.**—3300 volts 50 ∽. A 3-phase system is generally adopted on account of the greater safety of alternating motors in mines liable to fire-damp or dust, and as it affords facility for extension. Including requirements for ventilation, pumping, hauling, winding, etc., mines usually give an annual load factor of some 40 per cent.

6. **Rolling Mills.**—American practice has largely led to the adoption of direct-current plant, whereas English and Continental practice is in favour of 3-phase plant. More will be said of this in a later chapter dealing with this class of power plants. The average annual load factor is about 20 per cent.

7. **Textile and Grain Mills, etc.**—Three-phase 50 ∽ motors have an immense advantage over other types on account of the absence of commutation and the practical elimination of any chance of ignition of the fine dust usually found in such mills, and also on account of the constant speed so necessary in textile mills. Textile mills have an annual load factor of some 30 per cent., while paper and grain mills give a load factor of about 80 per cent.

8. **Shipyards, Arsenals, and Similar Factories.**—Though in many existing cases direct current has been adopted, 3-phase motors are being more generally used; they have considerable advantages in exposed positions, as in shipyards and wharves,

and require less attention. In all new works, therefore, a 3-phase system will probably be adopted. The average load factor is only from 18 to 22 per cent.

9. Chemical Works.—For metallurgical processes, as in the manufacture of carbide and similar products, alternating current with a frequency of 50 ∽ is invariably adopted. For the preparation of acids, alkalis, dyes, and so forth, direct current at a pressure of 100 volts is normally required. All these works usually have an extraordinarily high load factor, sometimes over 90 per cent., and the machinery must therefore have a generous rating as regards temperature, with a fair instalment of stand-by plant to allow for repairs and inspection.

10. Docks, Jetties, and Wharves.—Owing to the exposed positions of capstans and jib-cranes, 3-phase motors are recommended. Care must be taken to deal with, and if necessary to correct, the low power factor which is often experienced in such cases. Very low load factors are common, sometimes as low as 2·5 per cent.

Thury High-pressure Direct-current System.—This system has been adopted in several cases in Europe for long-distance transmission, the most notable cases being the 27,000-volt line between St. Maurice and Lausanne, and the Moutiers and Lyon transmission line of 112 miles at 57,600 volts. In this system the generators are run in series (eight 7200-volt generators being in series in the Lyon case), and one of the generators has to bear the maximum difference of pressure between line and earth (the earth being made use of as a return conductor). It would be impossible in practice to insulate the windings of such a machine, so the whole machine is insulated from earth, frame and windings alike, the armature being coupled to the engine or turbine by an insulated coupling. Special attention has also to be paid to the safety of the attendants, and the whole engine-house floor is therefore insulated. The protection is such that it is impossible for any employé to touch the machines and "earth" simultaneously. The engine-house floor has generally been constructed of a thick layer of asphalte concrete with an additional thin layer of pure asphalte, the machines being further protected by carriage on insulators.

CHAPTER II

PRELIMINARY NOTES ON THE CHOICE OF SITE AND TYPE OF PLANT

THE system of supply having been determined and the type and character of the electrical generating plant settled, the next questions to be considered are the kind of prime mover to be adopted and the choice of the power house site.

These two matters are often closely related and in some cases may be wholly or largely determined by another factor altogether, namely, the character or location of the ultimate source of the power. This is clearly so when it is proposed to harness a water power, and may be the case when the power is to be developed by the utilization of waste gases, especially if the cost of compressing the gases and conveying them to a distant power house site would be prohibitive.

It is unnecessary at the present stage to deal with special cases such as hydro-electric plants, the utilization of waste furnace gases in steel works, or the use of oil engines in small independent power houses. Separate consideration, however, is devoted to them in later chapters.

In general practice at the present time, the choice usually lies between steam and gas-driven prime movers. If the former be settled upon, there is the further alternative of turbines or reciprocating engines. In nearly all of the newer power houses, excepting the very small ones, turbines are now universally employed on account of their greater economy in capital outlay and in steam consumption, their higher speeds, and the reduction in the space occupied.

The principal points for consideration in determining between gas and steam-driven prime movers and upon the site for the power house are :—

(*a*) Size of unit of plant and average daily load factor of plant output.

(*b*) Accessibility of adequate supplies of condensing water and feed water.

(*c*) Cost of fuel and facilities for transport by rail or sea.

(*d*) Ground space required and the geological character of possible sites.

(*e*) Geographical position of power house and the relative costs and conveniences of possible alternative sites.

Preliminary notes on these points are set out below, and more detailed consideration is given to a number of them in subsequent chapters.

Size of Units.—The nature of the work, and the average load factor have to be considered as well as the reliability factor. Generally speaking, the higher the load factor the better is the case for gas engines in power houses of small or medium size.

It is well so to arrange the sizes of engines and boilers or gas producers that the estimated daily load curves may fit in with the units of plants installed in such a way that the latter may be run as nearly as possible at rated, or at the most economical, load. An ideally simple arrangement is, of course, one boiler to each engine or turbine (or in a gas plant, one set of producers to each engine) for this simplifies the pipe work and reduces the cost of the power house equipment. But as boilers are restricted in size, for reasons of economy and ease of handling, etc., this arrangement necessarily limits the available size of steam engine or turbine to, say, 5000 K.W. as a maximum.

A further consideration therefore arises in the case of large steam power stations, namely, the number of boilers requisite for each prime mover. This matter is dealt with in a later chapter (Chap. IV.).

Ideal Number of Units of Plant.—Eight complete units of plant have many advantages. The power house can then be worked so that six sets are in commission at rated load, one set is in reserve, and one set is always allowed to be dismantled. Since each set will be so designed as to be capable of developing a 25 per cent. overload for several hours without undue strain or temperature rise, there are in effect two sets in reserve for

emergency. Thus the safe rated load of such a station would be that of six units while the capital expenditure would be on eight only, i.e. on plant 33 per cent. in excess of the rated and commercial output. The effective reserve would be two sets with a third out of commission. As the safe output would really always be seven (either working at rated load or with six working on overload for the necessary time), the capital invested in reserve plant is thus only 14 per cent. of the whole.

In special cases of metallurgical or chemical applications where very high annual load factors are experienced, then no doubt the proportion of reserve plant would have to be increased, and, as a rule, the number of complete units would be smaller than eight. For general applications on a large scale, however, there is much to be said for this principle.

Water Supply for Condensing Plant and other Purposes.—If possible, of course, the power house should be laid out with a good river, canal, or sea frontage, so that circulating water can be obtained easily and cheaply. This is particularly important in the case of large steam turbo stations.

The consumption of water will be as follows (average conditions of humidity being taken for the cooling towers):—

TABLE III.

CONDENSING WATER: AVERAGE REQUIREMENTS.

Type of power house.	Climate.	Per B.H.P. hour.		Per K.W. hour.	
		Natural supply.	Cooling towers.	Natural supply.	Cooling towers.
		Gallons.	Gallons.	Gallons.	Gallons.
Steam .	Temperate	57·4	7·0	89·0	10·9
	Tropical	71·4	8·4	112·0	13·3
Gas . .	Temperate	7·75	1·0	10·4	1·4
	Tropical	12·0	1·6	16·0	2·25

Care has to be taken to arrange the circulating pipes so that they will not be liable to damage by shipping, and with due regard to the rise and fall of spring tides, and so that they will not silt up with mud and débris. This will be dealt with in

detail later in the special chapters devoted to the design of pipe work and condensers (Chaps. V. and VII.).

Feed-water Supply.—If the geological strata are such as to provide not only a good foundation, but also a supply of good feed water through sinking an artesian well or a bore-hole, the site will be more valuable, since the cost of pumping such water is usually much less than the cost of purchasing the water. Moreover, at such a site there would be no need for evaporating plant and reagent apparatus, which would be necessary were brackish or salt water used as a source of circulating water.

Cost of Fuel.—In determining the relative merits of steam and gas-driven prime movers for power houses of small or moderate size, careful attention must be given to the cost of the fuel available. This is a comparatively easy problem if alternative supplies, say of coal and power gas, can be brought to the site. If, however, it is a question of burning coal under boilers or of converting it into power gas on the site, considerations such as thermal efficiencies, and capital and operating costs must also be taken into account.

The general thermal efficiency of steam power stations is low, ranging from about 9 per cent. to 12 per cent., and the highest recorded thermal efficiency of a modern power station is 18 per cent. With the adoption, however, of higher steam pressures ranging from 350 to 415 lb. per square inch, of methods for reheating the feed water by means of steam taken from an intermediate stage of the turbine, of large generating plant and of other improvements, there will certainly be a considerable advance upon the latter attainment.

In the case of the internal combustion engine, the thermal efficiency under average working conditions ranges from 25 per cent. to perhaps 30 per cent. When account is taken, however, of the thermal losses incurred in making power gas from coal, coke, or anthracite, the thermal efficiency of a complete power house comprising gas engines and non-recovery gas producers will not, as a general rule, be greater than from 19 per cent. to 22 per cent. If ammonia recovery producers are installed, the overall thermal efficiency will be further reduced owing to the

large amount of steam required in the producer blast to ensure the maximum recovery of ammonia.

Generally speaking, the higher the price of fuel, the better is the relative economy of the gas engine and non-recovery gas producer for small or moderate sized power houses. The installation of ammonia recovery plant at gas engine power houses of moderate size will also prove profitable in places where coal is cheap and labour charges low and where a market exists for ammonium sulphate. With the present limitations to the sizes of gas engines and producers, the advantages diminish with increasing sizes of power house owing to the multiplication of units and of heavy foundations and the consequent increases in the capital outlay (and capital charges), in labour costs and in the cost of repairs. For large power houses, steam turbines are therefore almost invariably installed unless there are very special reasons to the contrary.

Accessibility for Coaling.—Regard must be given to railway sidings or to wharfage and tidal facilities for coaling. A site having ready access by rail and also by water has great advantages from the point of view of coal supply and ash disposal.

The average annual amounts of coal which have to be dealt with at large stations are as follows (based on an average calorific value of 13,500 B.Th.U. per lb.) :—

TABLE IV.

COAL REQUIREMENTS OF LARGE STATIONS.

	Tons per annum.	Tons per diem, average.	Tons per annum.	Tons per diem, average.	Tons per annum.	Tons per diem, average.	Tons per annum.	Tons per diem, average.	Tons per annum.	Tons per diem, average.
Load factor.	20 per cent.		30 per cent.		40 per cent.		50 per cent.		60 per cent.	
Steam plant per 1000 K.W. installed	2740	7·5	3800	10·5	4700	13·0	5400	15·0	6000	16·5
Gas plant per 1000 K.W. installed	1200	3·3	1825	5·0	2360	6·6	3100	8·5	3600	9·9

For large stations, it is clear that the wharfage or jetties for unloading coal and other materials may represent a considerable capital expenditure.

In many stations situated abroad, or in places where coal can be more economically borne in large steamers, or where by reason of geographical position coal can only be intermittently delivered, space has to be found for bunkers, coal silos and coal dumps of sufficient capacity to provide adequate reserves. Regard must also be paid to maximum temperature, depreciation of coal, and prevention of spontaneous combustion. This matter is dealt with under the special section devoted to Steam-raising Plant (see Chap. IV.).

Area Required.—In the matter of area required by steam or gas engine plant there is little to choose. The following Table (No. V.) will give, approximately, the area required for stations ranging from 10,000 to 120,000 K.W., provided the boilers are all on the same plane (and not arranged on two decks, as in the case of some large power houses). The figures include coal silos for the larger stations. The variations in the figures (which are taken from actual examples) are accounted for by the different designs adopted).

TABLE V.

GROUND SPACE FOR STEAM POWER STATIONS.

Plant installed.	Type of unit and power house.		With natural circulating water supply.				With cooling towers for circulating water.			
K.W.	Single deck = S.D. Double deck = D.D.		Area per H.P.		Area per K.W.		Area per H.P.		Area per K.W.	
			Sq. yds.	Sq. metres.	Sq. yds.	Sq. metres.	Sq. yds.	Sq. metres.	Sq. yds.	Sq. metres.
13,000	Reciprocating	S.D.	0·331	0·278	0·444	0·371	0·407	0·340	0·546	0·455
60,000	do.	do.	0·192	0·160	0·257	0·215	0·223	0·186	0·299	0·250
10,000	Turbines.	do.	0·164	0·137	0·221	0·185	0·263	0·220	0·353	0·295
28,000	do.	do.	0·121	0·101	0·162	0·135	0·162	0·135	0·217	0·181
48,000	do.	D.D.	0·136	0·114	0·183	0·153	0·173	0·145	0·232	0·194
120,000	do.	S.D.	0·151	0·126	0·203	0·169	—	—	—	—

GROUND SPACE FOR GAS ENGINE PLANTS.

Plant installed.	Type of unit.	With ammonia recovery gas producers.				With non-recovery gas producers.			
		Area per H.P.		Area per K.W.		Area per H.P.		Area per K.W.	
K.W.		Sq. yds.	Sq. metres.	Sq. yds.	Sq. metres.	Sq. yds.	Sq. metres.	Sq. yds.	Sq. metres.
1000-12,000	Horizontal	0·746	0·623	1·000	0·836	0·620	0·518	0·831	0·695

Foundations: Geological Considerations.—Attention must be given to the foundations of the proposed site and to the contour of the ground. Riverside sites are, as might be expected, often on alluvial flats, and borings must be taken to ascertain the nature of the substrata and their capability of carrying heavy weights. Concentrated weights up to 15 tons per square foot have to be arranged for as in the case of main stanchions carrying the dead load of the roof and an over-head crane with live loads. A good bed of stiff clay, marl or compact gravel—provided there is no underlying stratum of sand or peat—will make an excellent foundation. In some cases, however, the site may be covered with alluvial mud or sand, when it will be necessary to drive piles into the underlying subsoil and to float the site with a concrete raft. Such a procedure is costly but may be justified by the other advantages accruing from the position.

Position of Site: Buildings.—Care has to be exercised in fixing the datum line of power houses. The relation to the water level of the condensing water supply, whether sea, river, or lake, has to be fixed, especially in tidal rivers or estuaries. The limits of spring and ebb tides and of flood levels fix (*a*) the levels of the condenser pipe line, and (*b*) the levels of coal jetties and also of the engine-room. Upon these in turn depend the excavation necessary on the site and therefore the cost of the building. This necessary excavation as a rule clears away the softer material overlying the site and enables a firm foundation to be obtained; and in many cases excellent gravel and sand can be reclaimed for use in the concrete required for foundations or reinforced walls. The cost of approach roads has in some

cases to be borne—and in others a cable tunnel for some distance out from the power house. There are many other considerations, such as the cost of local stone, or bricks, cement or relative cost of reinforced concrete. For power house construction, especially if of large capacity, a steel work structure with filled-in panels of brick or of concrete is as a rule desirable and cheaper. The boiler-house structure being required to carry large over-head bunkers, and the engine-room stanchions having to carry the roof principals and large cranes, a strong and at the same time a cheaper construction can thus be obtained. Especially in the case of power houses in remote districts abroad is this desirable, provided there is no insuperable or commercial difficulty in transporting the heavy stanchions and members to the site.

Future Development.—In laying out a power house it is well to look some way into the future and design at once for what is estimated to be the total requirements, even if only a small part is immediately to be built. The Author has learnt from experience the necessity of doing this, and now always prepares a key plan for the whole site and ultimate complete plant from which the detailed plans for the first section are prepared. It is true that subsequent development may modify the original lay-out in some details, e.g. owing to the use of larger units than those originally contemplated. But as the capacity of the site is really limited by the space available for steam-raising or gas-producing plant and coal storage, the principal points of the original design need not be impaired by subsequent development.

Standardization.—In designing a power house it is of great importance to standardize as far as possible. Having determined the most useful size and type of plant, boilers, pumps, condensers, or gas plant, as the case may be, auxiliaries and switchgear, it is quite easy to arrange interchangeability of sets and of parts. Thus, in the case of water-tube boilers the number of spare tubes, fire bars, superheater tubes and bricks can be reduced by arranging for all boilers to be uniform in size and type. Spare pistons and valve rings, governor parts, brasses, eccentric straps, oil pumps and motion gear, or even spare cranks can be easily carried as part of the equipment in a re-

ciprocating engine installation; or spare blades, wheels, nozzles, governor parts, oil pump and other accessories in the case of a turbine plant; also spare tubes and ferrules or air pump parts for the condensers; spare feed pump parts; spare valves for the pipe range; and spare switches and instruments, insulators, etc., for the switchgear. All this reduces capital expenditure, saves room and cost of repairs, and makes things more orderly in the administration of the power house. This means a great deal, especially when the situation is a remote one, as in the colonies or a foreign country, where spare materials take a considerable time to be delivered when ordered from a distance. More will be said of these matters when dealing with the particular parts of the power house equipment.

In British practice it is becoming increasingly the vogue, and very properly so, to adopt the standards prescribed by the British Engineering Standards Association. By adopting standard pipe flanges and bends, for instance, right through, there are never any bastard sizes of joint rings or odd bolts and nuts to be kept in stock.

Simplicity of Design.—The Author has elsewhere remarked that "simplicity is the hall-mark of good design". Speaking as one who had for many years the control of public supply stations, the Author cannot too strongly urge the importance that should be attached by the designer to a *simple* lay-out of any power house. This applies more particularly to the pipe work and auxiliaries, arrangement of flues, dampers, and to the switchgear. It also, of course, applies to the design of the various parts of the plant itself. Accessibility for inspection of boilers, for removal of soot from flues, for ready handling of parts of engines and condensers, and for cleaning and inspection of switch equipment is essential. Avoid any "cranks" in the design, though progress will never be made unless some engineers are courageous enough to try new inventions. The latter, however, should only be adopted (or well tried and proved types should only be departed from) after a most careful investigation.

After these preliminary and general remarks, the various sections of the power house and types of plant can be dealt with in practical detail.

CHAPTER III

BUILDINGS

Architecture of Power House Buildings.—Considerable differences occur in the architecture of large power houses in various countries. In America, towns are generally planned or set out in squares or blocks, which make it difficult to obtain large sites within the city; also the price of land is high as a rule. When the power house is situated within the town, the practice is to adopt a rectangular building covering a part or the whole of one block. The most is made of its value, and a considerable installation of plant is obtained by arranging the plant in several decks or stories. In the case of other intra-mural stations in other countries, a good deal has to be expended on architectural features, such as stone facings or ornamental stone and moulded work, so as to make the structure harmonize with the surrounding buildings, and thus not detract from the amenities of the district in which it is built. Further, the increasingly stringent building bye-laws of various cities, and the great precautions which have to be taken against vibration, noise, smoke or steam nuisance, all increase the cost of foundations, shafts, etc.

On the other hand, when the power house is erected at a distance from the city, the same regard has not to be paid either to ornamentation or to possible litigation from nuisance. This does not mean that an ugly structure need be erected, for a well-designed building need not be unnecessarily expensive, and regard can be paid to a nicety of architectural design. The engineer must make the outline design and lay-out of the power house, leaving the architect to clothe the structure and to co-operate with the engineer on the question of foundations.

One of the designer's initial problems, therefore, is to

determine the differences in capital outlay between an ornate building situated on a more costly site (but near the network or load the plant is to supply), which on a pre-war basis may roughly be calculated at 9d. per cubic foot, or £3 5s. per K.W., and a less costly building situated at a distance from the city, to which must be added the cost of the transmission mains plus the cost of a receiving sub-station or switch-centre for distribution. Such an outside station in some districts may have the walls raised only to engine-room level, and covered in with galvanized iron sheets above. In addition, the extra cost of coal carriage to the inside site, and of removal of ashes (and in some cases the additional cost of water and circulating pipes, or even cooling towers and the extra ground they occupy), must be calculated and balanced against the extra transmission losses from, and the possible reduced efficiency of, the outside power house system.

As an instance of the wide difference between modern conditions and those of only a few years ago, there are no less than thirty-eight public supply stations within the County of London, which involved an expenditure of £3,500,000 on buildings and land alone to accommodate some 160,000 K.W.—or £21·9 per K.W. installed. The Engineering Board (of which the Author was a member) who advised the London County Council from 1905 to 1907, designed a 120,000 K.W. power station to be situated down the river Thames. The land and buildings were estimated to have cost £394,000, or £3·28 per K.W. available within the county after transmission; and a proportion of the transmission lines, as well as the various sub-stations, were estimated at about £1,000,000, making a total of £1,394,000, or £11·6 per available K.W., as against the £21·9 cited above.

Foundations.—The question of foundations enters largely into the design of power houses, and affects the disposal and distribution of the heavy loads. The latter are principally concentrated on the stanchions carrying the bunkers and on the stanchions of the engine-house with a heavily loaded travelling crane. Some three-quarters of the whole load is concentrated on one-half of the site, the turbines, etc., which make up the remaining quarter load being distributed over the other half. The

effect of vibration is thus increased greatly, and in some cases, with reciprocating engines, there are difficulties in preventing this vibration from being transmitted to a distance, more especially when the site covers compressible or water-logged soils. When such sites are compulsory, reinforced piles may be driven either over the whole site, or at points of concentrated load such as under stanchions, and bound together with a reinforced concrete raft, so as to increase the carrying capacity of the soil and to prevent it from exuding or working out from under the foundations, and also to reduce the tendency to increase any vibration or to transmit it to a distance.

In some cases of intra-mural power houses—especially those built on alluvial strata—expensive concrete basement structures have to be adopted, and these are to be avoided wherever possible, as they increase the cost of a building enormously, with, as it were, nothing to show for it. As has been said before, there is the further consideration that long lines of large pipes or concrete culverts have to be laid from the power house to the source of the condensing water supply, as it is almost impossible commercially to use cooling towers in such instances.

Altogether, therefore, the modern tendency, and rightly so, is to go outside a city and to choose a site—for whatever purpose the power house is required—where land is cheaper, building easier, and coal accessible, with the additional facility of a plentiful supply of circulating water. For gas-driven power houses an outside site is absolutely necessary. The established development of high-tension 3-phase supply has made the choice of sites much less confined to a small area, so that there is in all modern instances a greater freedom in the choice of sites with a resultant economy in negotiations for the purchase of land in a suitable locality.

In the Manhattan Railway Company's power house, New York, there is room to install 150,000 H.P. The site is 560 feet by 204 feet, or 12,700 square yards in extent and 66 feet from parapet to the top of the granite base. The building consists of a skeleton steel structure, with double decks, with heavy enclosing walls, the base being of granite, and with brickwork above, covered in with a red-tiled roof. The windows are all in

the upper parts of the building, and are very large, being 45 feet high by 14 feet wide and spaced 35 feet apart, thus giving good light. The engine-room is 93 feet wide by 128 feet long by 107 feet in height, and contains eight 10,000 H.P. reciprocating engines, the height of each being 42 feet from foundation to top. Each steam generator weighs 400 tons. Contrast this with a turbine installation of like units, especially with regard to the height of the engine-room, which could easily have been reduced to 60 feet, thus entirely remodelling the design of the power house and enormously reducing its cost.

The boiler house is 104 feet wide by 128 feet long by 128 feet in height, and contains bunkers with a storage capacity of 15,000 tons, carried on stanchions spaced 20 feet apart longitudinally and with 15-foot centres transversely. Each stanchion carries a load of 500 tons. There is a total of 6000 tons of steel used in the structure, or 100 tons per 1000 K.W. capacity of station. The maximum working stress on the steel throughout on the whole design is taken at 6 tons per square inch, thus giving a factor of safety of 4 to 5. In this case there are four brick circular shafts, each 278 feet high by 17 feet internal diameter at the top, carried on octagonal bases 73 feet from the ground level. The Manhattan power house is built on an uneven foundation of gneiss rock of unequal supporting power. Considerable variation in the thickness of the concrete foundation was therefore necessary so as to distribute the weight.

As power houses frequently have to be erected on river-side sites, the subsoil is usually not suitable for such heavy weights without some assistance. A careful adjustment of the weight is necessary, since the alluvial soil will resist in some places and yield in others. When it is soft or water-logged the superincumbent load should be carried on concrete floats proportionate to the loads carried, and of rather more than one and a half times the thickness or strength which would be taken for an ordinary building of similar size. This is good practice on clay soils. The concrete float should, however, be keyed on the underside on sand and looser soils.

At the Calcutta power house, where the soil is an alluvial mud—soft and compressible—a continuous concrete float was

adopted, and carried a load of 1 ton per square foot without appreciable settlement.

In Amsterdam the same plan was adopted, but in that case the subsoil was first consolidated by driving piles, placed so as to take up the concentrated loads brought down designedly to various points.

At Bahia Blanca, where the soil is a water-logged sand 10 feet 6 inches in thickness, lying on marl, the Author and his colleagues adopted reinforced concrete piles, driven into the underlying marl, and concentrated the piles under the main stanchions and engine foundations, floating the whole with a concrete raft reinforced with old steel rails. Fifteen tons per square foot was concentrated on the stanchion foundations.

At the Kingsbridge power house, New York, the subsoil is a fine sharp sand. In this case some 15,000 oak piles 40 feet long were driven 28 inches from centre to centre, and a raft of concrete 8 feet thick was then laid over the whole site, mixed in the proportion of: cement 1; sand 2; stone 4 parts. The maximum bearing weight in this case is also 15 tons per square foot.

The weights usually allowed for in designing the structures and floors (in addition to the weight of floors themselves) are as follow:—

Boiler-house firing floor	.	1120 lbs. per square foot.
Engine-room floor	. .	1120 ,, ,,
Switchboard galleries	.	336 ,, ,,

Safe Carrying Power of Foundations.—The following Table, No. VI., gives the load-carrying power of various subsoils:—

TABLE VI.

LOAD-CARRYING POWER OF SUBSOILS.

Subsoil.	Load-carrying power.
	Tons per sq. foot.
Hard rock	250
Compact gravel	4
Ordinary or confined sand	4
Hard clay or chalk	2
Soft clay and wet or loose sand . . .	1·0

In yielding or water-logged soils, piles of reinforced concrete must be driven, with a concrete float or raft overlaid on them.

Rankine gives the following formula for the greatest deadload (in tons) which a pile will bear without further sinking:—

$$P = \sqrt{\left(\frac{4ESWH}{L} + \frac{4E^2S^2D^2}{L^2}\right)} - 2\frac{ESD}{L}$$

where W = weight of ram or monkey, in tons;
H = height of fall of same, in feet;
D = depth driven by last blow, in fractions of a foot;
S = sectional area of pile, in square inches;
L = length of pile, in feet;
E = modulus of elasticity of material of pile, in tons per sq. in.

The machinery foundations must be entirely separate from the main walls so as to minimize or eliminate vibration. Firm foundation subsoils such as clay and rock easily transmit vibration which may reappear at some distance from the power house. Looser subsoils do not transmit vibrations so readily. For turbine work no real difficulties exist, but with reciprocating engines special care must be taken to have good substantial concrete blocks with widened and extended bases, while in some extreme cases a layer of sand, or of hair felt, or of india-rubber, is necessary.

The following safe loads on foundations may be used:—

TABLE VII.

Safe Loads on Foundations.

Nature of foundation.	Safe carrying load in tons per sq. foot.
Good concrete	4
Steel rails in concrete	8
Concrete piles	12
Ordinary bricks in cement mortar	5
Hard bricks ditto	8
Blue bricks ditto	12

Setting out Foundations.—Templates are used to set out

accurately the positions of bolt holes for the machinery foundations. Holes should be left in the concrete to receive the foundation bolts, with side holes at the bottom to give access to the plate and cotter. Removable wooden core-boxes are usually fixed while the concrete is being put in. The foundation block, when completed, should be surfaced off in neat cement and strickled or stoned up to a true and uniform surface. When the concrete has set, the machine is then lifted into position, set up on steel wedges, aligned and trued up, and the interstices are filled with semi-dry cement and granite chippings rammed into place.

Fireproof Buildings.—It is almost unnecessary to say that all power houses must be made non-inflammable; no wood should be used in the whole of the structure. Even to use wood shingling as ceiling boards is a grave mistake, since with high-tension switch-gear there is a possibility of incandescent oil or flames being shot out to a great height, when such boards, necessarily as dry as tinder, will catch alight with ease. The Author has found that a very good roof, non-inflammable and light, but strong, can be made of eternit sheets or ceiling boards used as an inner lining to the roof, with slate or eternit outside roofing materials. A detail of this is shown in Fig. 1. Excluding labour for erection (which would be similar in both cases) the pre-war cost was 8s. 9d. per square yard, as against 6s. 9d. per square yard for ordinary slating and wood lining. Window frames should be of iron, but small doors can be of wood, as being from their positions unlikely to catch fire. Large doors can be of the Kinnear rolling type with advantage. The power house site should be isolated so as to prevent danger from fire breaking out in, and spreading from, neighbouring property.

American Specification: Structural Steel.—The American standard specification for structural steel contains the following provisions:—

(*a*) The steel to be made either by the open hearth or Bessemer process.

(*b*) The steel not to contain more than 0·1 per cent. of phosphorus.

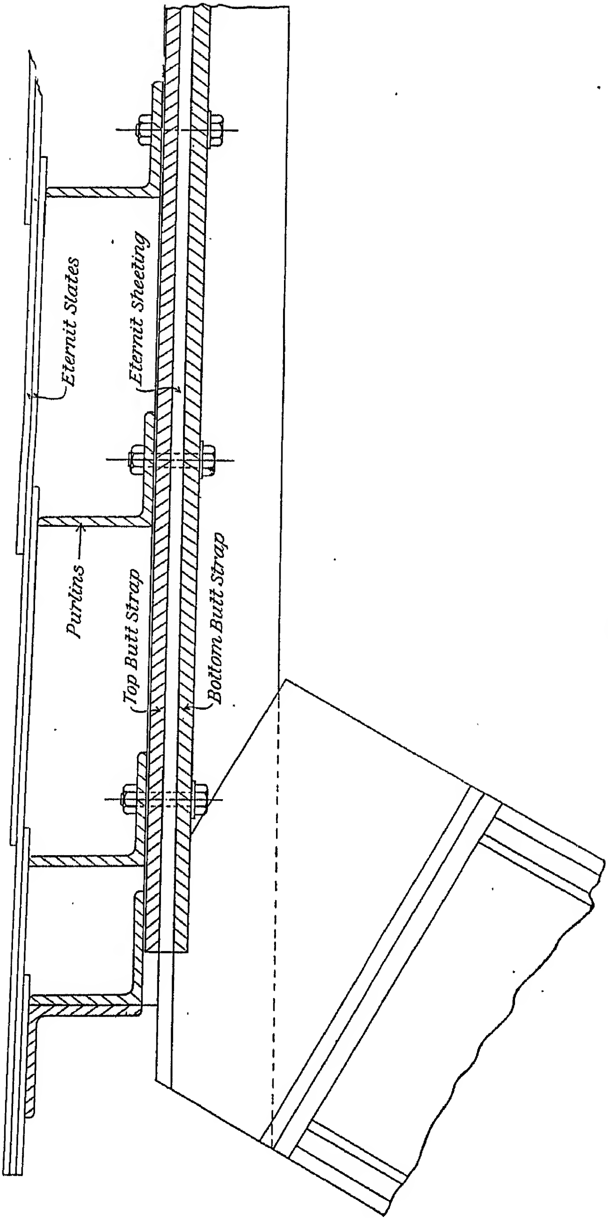
Eternit Slates
Eternit Sheeting
Purlins
Top Butt Strap
Bottom Butt Strap

FIG. 1.

(c) The steel is divided into two classes, viz. (1) rivet steel, and (2) medium steel, the following qualities being specified:—

	Rivet steel.	Medium steel.
Tensile strength	22·33 to 26·8 tons	26·8 to 31·2 tons
Yield point, not less than . . .	13·5 tons	15·6 tons
Elongation in a length of 8 ins. . .	26 per cent.	22 per cent.

Slight variations are permitted in materials less than $\frac{5}{16}$ inch and more than $\frac{3}{4}$ inch in thickness.

The following further tests are also specified:—

(a) The rivet steel to be capable of being bent cold 180° flat on itself without signs of fracture on the outer edges.

(b) The medium steel to be bent cold 180° around a diameter equal to the thickness of the specimen tested and without signs of fracture on the outside.

The low carbon steels usually answer to the following analyses:—

Carbon	from	0·17	per cent.	to	0·27	per cent.
Silicon	,,	0·02	,,	,,	0·09	,,
Phosphorus	,,	0·10	,,	,,	0·05	,,
Manganese	,,	0·05	,,	,,	0·07	,,
Sulphur	,,	0·01	,,	,,	0·04	,,

These steels, therefore, have similar properties to wrought iron, except that their strength is greater, their ductility is greater, and the fracture shows a fine silky and velvet-like appearance.

In compression the yield point is the same as that in tension, while the shear strength is about four-fifths that of the tensile strength. The values are, of course, affected by increase of temperature.

British Specification.—The British standard specification for structural steel includes the following provisions:—

(a) All plates and bars to be made by the open hearth or Bessemer process, acid or basic, and not to show on analysis more than 0·06 per cent. of sulphur or 0·07 per cent. of phosphorus.

An analysis of each cast is often required from the manufacturer.

(*b*) No plate or section to be more than $2\frac{1}{2}$ per cent. over, or $2\frac{1}{2}$ per cent. under, the calculated weight.

(*c*) The following properties are also specified :—

	Plates, angles, bars, etc.	Rivet bars.
[illegible]	28 to 32 tons	26 to 30 tons
[illegible]ngth of 8 ins. .	20 per cent.	25 per cent.

For materials not less than $\frac{5}{16}$ inch in thickness bending tests only are required. With rivet bars bending tests are not required.

(*d*) In both cold and temper bending tests, the pieces to withstand without fracture being doubled over until the internal radius is not greater than one and a half times the thickness of the test piece.

The above are the leading particulars, and the designer is referred to the actual standard specification for further details.

No cast work should be used in steel structural buildings, owing to its unreliability. It is usual to calculate steel members so that the maximum stress, counting in all possible forces (such as dead weight of structure; wind pressure, calculated at 40 lbs. per square foot; and moving loads, such as the overhead crane loaded with maximum lift, bunkers, fuel, etc.), shall not exceed 8 tons per square inch. This will give a factor of safety of from 3 to 4 under a combination of the maximum stresses possible. It is also usual so to design the stanchion bases that the concentrated maximum load on the foundations shall not exceed 15 tons per square foot.

Weight of Steel Structure.—The weights of steel structures for power houses are as given below, the example being taken from an actual power house built to the Author's requirements.

In the case of a building which enclosed an area 21,924 square feet and a volume of 1,096,100 cubic feet the weights were as follows :—

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	Tons
A. Structural steel work, including stanchions, girders, joists, roof principals, bracings, purlins, stairs, window-frames, doors, galleries, gulleys, and down pipes	562
B. Coal bunkers and ash bunkers, exclusive of stanchions included under A	158
C. Steel chimney. (The bricks for lining and for base plinth weighed 44 tons)	26
Total	746

Generally speaking, the weight of steelwork necessary for power house structures having overhead bunkers, condenser basement, and switchboard galleries, may be calculated at the following rates:—

Power House 5000 to 10,000 K.W. { 150 tons per 1000 K.W. normal rating, 36 tons per 1000 square feet enclosed, 0·68 ton per 1000 cubic feet enclosed;

reducing proportionately to—

80,000 to 100,000 K.W. { 75 tons per 1000 K.W. normal rating, 18 tons per 1000 square feet enclosed, 0·34 ton per 1000 cubic feet enclosed.

Brickwork.—In steel skeleton structures the wall panels can be either of concrete or of brickwork. These afford some measure of support to the steel stanchions, but the stanchions should nevertheless be calculated without this uncertain assistance. The walls merely have to sustain their own weight and the wind pressures on their surfaces.

The following thicknesses (Table No. VIII.) are required by the London Building Acts:—

TABLE VIII.

THICKNESS OF WALLS.

Height.	Thickness.
30 feet	$17\frac{1}{2}$ inches reducing to $8\frac{1}{2}$ inches
40 ,,	$21\frac{1}{2}$,, ,, 13 ,,
50 ,,	26 ,, ,, 13 ,,

The following is an extract from the London Building Act, 1894:—

"If in any storey of a building of the warehouse class the thickness of the wall is less than one-fourteenth part of the height

of such storey, the thickness of the wall shall be increased to one-fourteenth part of the height of the storey and the thickness of each external wall and party wall below that storey shall be increased to a like extent, but any such additional thickness may be confined to piers properly distributed, of which the collective widths amount to one-fourth part of the length of the wall."

In the New York Building Laws it is specified that the thickness of walls shall be as follows (Table No. IX.), when the clear width of the building is 50 feet :—

TABLE IX.

THICKNESS OF WALLS.

Height of wall.	First section.		Second section.	
	Height.	Thickness.	Height.	Thickness.
ft.	ft.	ins.	ft.	ins.
40	40	24	—	—
60	40	28	Top	24
75	25	32	Top	28

The above is, of course, for plain brickwork structures and without steel framework. For practical purposes the former table could be better taken as a guide.

The brickwork footings are usually arranged twice the width of the lower walls.

It will be useful to point out that—

1 rod of brickwork = 272 super feet $1\frac{1}{2}$ bricks in thickness
= $11\frac{1}{3}$ cubic yards
= 4850 bricks on average work.
330 stock bricks = 1 ton in weight
" " = 55 cubic feet.

The crushing strength of bricks is as follows :—

London stock bricks . .	140 tons per square foot
Wire-cut bricks . . .	260 " " " "
Blue Staffordshire . .	360 " " " "

The resistance to crushing of brickwork built in cement is about $\frac{1}{3}$ that of the bricks with which it is built.

621.31042

Reinforced Concrete and Stonework. — The crushing strengths of various building stones are as follows:—

Sandstone . .	300 tons per square foot.
Limestone . .	500 to 700 tons per square foot.
Whinstone (basalt) .	1000 tons per square foot.
Fine grain granite .	1500 ,, ,, ,, ,,

As a rule, stone structures are expensive, but are requisite in some countries where these materials are more easily obtainable, or in some intra-mural power houses where the architectural features are of importance.

Reinforced concrete can be used with good effect for the wall-panelling between stanchions. The thicknesses of walls in such cases are usually as follows (extract from the London Building Acts) for steel skeleton-framed buildings:—

"**Thickness of Walls.**—Enclosing wall for topmost 20 feet of its height to be not less than 8½ inches thick, remainder not less than 13 inches brickwork, terracotta, concrete, or other material to be executed in Portland cement-mortar, bedded close up to the metal framework, without any intervening cavity, all joints made full and solid."

The reinforced concrete is usually specified to be made in the proportion of 1 of Portland cement to 2 of sand and 4 of fine gravel, reinforced with steel wires No. 10 in thickness and interwoven. Portland cement will stand not less than 400 lbs. per square inch when tested in briquettes after one week's immersion in water, and will improve with age. Tests of higher values are often obtained.

The compressive strength of cement is stated to be 150 to 250 tons per square foot, and the strength of various mixtures as in Table No. X.

Good concrete depends on the cement used, the composition of the aggregate, thoroughness of mixing, the proportion of cement to aggregate, and on the age. Dr. Deacon found, in a series of tests in the great dam at Lake Vyrnwy, that the concrete used in that structure stood a compressive strength of 107 tons per square foot after one month, and 185 tons after 36 months. A reference may be made to the specification on page 80.

TABLE X.

COMPRESSIVE STRENGTHS OF CEMENT MIXTURES.

(POPPLEWELL.)

Mixture.		Compressive strength in tons per square foot.	
Sand.	Cement.	After 7 weeks.	After 20 weeks.
1	1	80	100
2	1	30	50
3	1	25	30
4	1	20	25
5	1	15	20

Interior of Power House Buildings.—Cleanliness, good ventilation, good lighting, and good drainage are essential. The boiler-house walls are usually left finished in neatly pointed brickwork, which, as a rule, is not glazed. The settings of boilers and economisers, and exposed flue-walls should be finished in second quality white or cream-glazed bricks, not only for cleanliness, but especially to reduce air leakages through porosity. This is dealt with in the chapter on boiler settings. The interiors of pump-rooms and engine-rooms should be finished in glazed bricks, these usually being a brown or green brick up to dado height, with a string course to finish and white glazed bricks beyond. Arches are usually of coloured glazed brick to give the engine-room a pleasing appearance. If the stanchions are brick encased, the corners should be of bull-nosed bricks. Buttresses in smaller power houses are similarly finished. The joints should be then raked out and finished with Parian cement; this prevents lodgment of dust. Sometimes the insides are faced with glazed tiles, as in the case of reinforced concrete panels. The tiles should be keyed. The inside walls are sometimes finished smooth with Parian cement; this is not to be recommended, however, owing to its tendency to disintegrate and to stain if there be any trace of oil vapour in the air of the engine-room. The floors of the engine-room and switchboard galleries can be finished in limestone mosaic, which answers

very well and is decorative, or in tiles. The boiler house should be paved with a hard stable brick, which will not chip easily, nor tend to disintegrate if hot ashes are pulled out on to the floor, and will wash down quickly. In condenser basements, the floor is usually finished in cement rendering. The concrete walls of the engine or turbine foundations can be finished smooth in cement. In some cases, where, owing to the exigencies of the site, some galleries are dark, the switchboard floor is finished in thick glass prisms set in a cast-iron framework, so as to allow passage of light to the gallery beneath. Stairways should be constructed of iron, but with wooden non-slip treads, or they may be dangerous to employees. Storage battery rooms must be specially treated. The walls are usually left finished in first quality ordinary bricks. The floors can either be of hard bricks, similar to those used in the boiler house, and laid with a good fall to several drainage gulleys, or laid with a similar fall in a special asphalte which must be acid-resisting. Good ventilation is especially necessary, so as to prevent the acid fumes from escaping into the engine-room or other parts of the power house.

Ventilation of Power House.—A proper system of ventilation for the boiler house and engine-room is necessary. In the boiler house there is little trouble, owing to the doors, windows, and the ventilating louvres in the roof. Indeed, when account is taken of the displacement of air necessary for the combustion of the fuel in the furnaces, the architectural details of the boiler house have to be considered carefully if only to provide comfort for the staff and prevent unnecessary draughts. In the engine-room, however, the problem of ventilation is more difficult. There should be no roof fanlights, owing to the difficulty in keeping them weather-tight and the chances of rain and snow driving in and dropping on the electrical plant. The engine-room should thus be arranged as loftily as is consistent with first cost, with clerestory windows (operated from the floor level) arranged in the side walls. Good ventilation can be obtained by arranging large windows at the gable ends. Sometimes forced ventilation is necessary in hot climates.

Fire Protection.—A complete system of hydrants should be

fixed throughout the building, commanding the coal bunkers and all parts of the structure. Regulation hose and nozzles can be fixed in cabinets at strategic points, readily accessible. Fire drill should be regularly undertaken so as to have the staff ready for emergencies. Buckets of sand must be placed in accessible positions on the switch galleries and cable tunnels or galleries.

Stepney Power House.—Fig. 2 is an illustration of the Stepney (London) Municipal power house built to the designs of Mr. W. C. P. Tapper. The cost of the buildings for accommodating 6000 K.W. of steam plant, was only £2·85 per K.W. installed, and therefore exceptionally low. They consist of a steel skeleton panelled with ferro-concrete and built to the regulations of the London County Council. The engine-room and boiler house are particularly well lighted—the whole of the roofs, excepting the middle portion of the latter, being glazed with wire-netting glass. The temporary end is of corrugated iron-sheeting, covered inside with a preparation of cork dust so as to prevent sweating.

Bahia Blanca.—This power house at present contains five 1250 K.V.A. triple expansion steam turbo alternators (6600 volts, 3-phase, 50 ⁓) with Le Blanc surface condensers and pumps; and seven Babcock boilers, each evaporating 23,000 lbs. per hour, with economisers, forced draught fans, and underfeed stokers. The area occupied is 3·8 square feet per K.W., and the volume 228 cubic feet per K.W.; the pre-war capital cost of the building in English equivalent being £4·5 per K.W.

A liberal amount of room was given by the Author to the spacing of the plant on account of the high temperatures experienced in midsummer. The boilers are set back from the wall for some distance, as shown in Fig. 31, the space at their backs being occupied by the economisers, feed pumps, hot wells, and Venturi meters, and by the Lea recorder, as well as by the access gangways to the flues. At the front of the boilers Kinnear roll-top doors have been fixed, which may be kept open during very hot weather and closed in bad weather or during dust storms.

Gas Engine Power Houses.—The cost of buildings for a gas

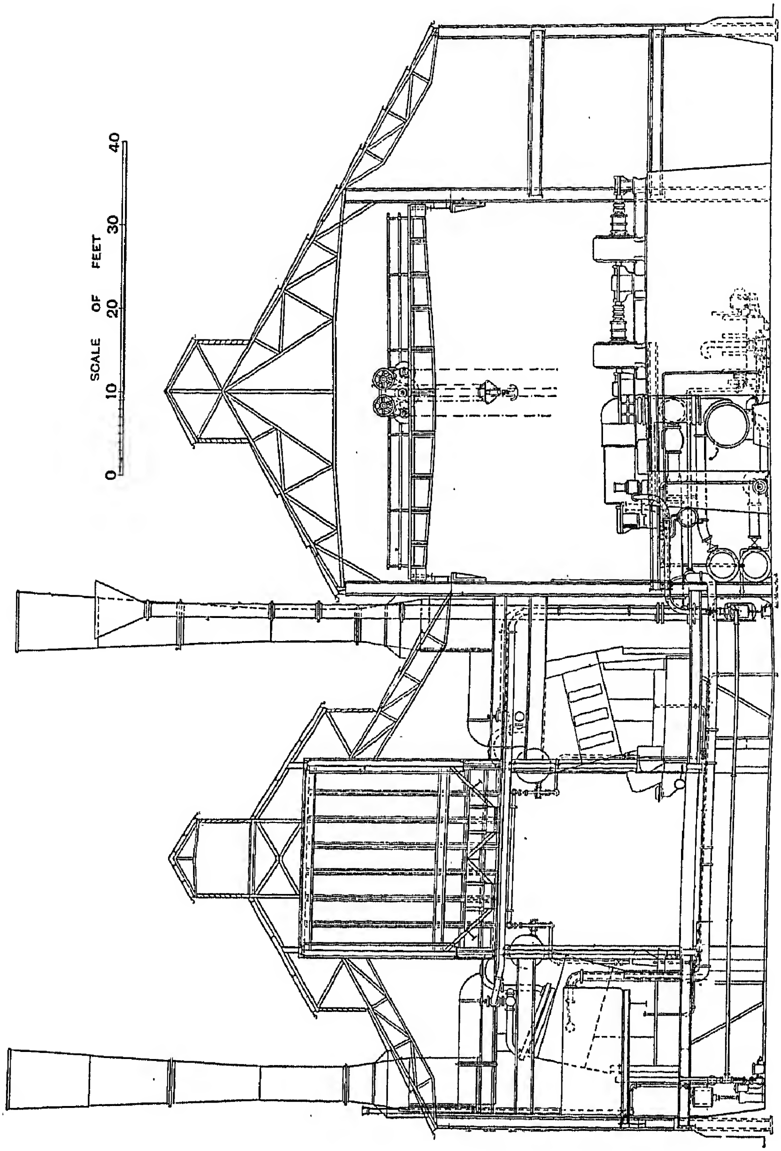

FIG. 2.

engine power house is approximately illustrated by the following examples, the figures, of course, relating to pre-war conditions.

For a steel-framed structure with brickwork filling and slate roof, complete with stanchions and walls, foundations and floors, floor tiling and inside glazed brick dado 6 feet high, covering an area of 103 × 250 feet, or 25,750 square feet, the cost amounted to £13,000, or 10s. per square foot. The mean height was 43 feet, so that the volume was 1,106,250 cubic feet, and the price per cubic foot about 3d. The building housed 10,500 K.W., and thus cost £1·24 per K.W., exclusive of engine foundations.

For the same class of building for a larger power house designed to accommodate 20,000 K.W., and covering an area of 260 × 250 feet at the same mean height of 43 feet, the cost was £24,000, equivalent to 7s. 6d. per square foot, 2d. per cubic foot, and £1·2 per K.W. installed, again omitting engine foundations. It must be remembered when comparing the costs of buildings for steam-driven and gas engine power houses, that there is no boiler house in the latter ; also that the area and volume required are only 3·25 square feet and 140 cubic feet respectively per K.W. installed, as compared with 4·7 square feet and 235 cubic feet respectively in ordinary large-sized steam turbine power houses. Plate I. represents a section through the 20,000 K.W. gas power house.

As a further example, estimates were prepared for brickwork buildings designed to accommodate five 2000 K.W. gas-driven sets. In this case there was no steelwork structure, the buildings being of brickwork throughout, the walls, of course, being of the normal thicknesses. The area covered was 300 × 206 feet, and the mean height 43 feet. The estimate was as follows :—

	£
Excavation	2500
3-inch concrete and foundations throughout	4875
Brickwork	3125
Roof principals	3300
Slating	900
Plumbing and other trades	500
Contingencies, etc.	1600
Total	£16,800

representing a cost of 5s. 5d. per square foot, 1½d. per cubic foot, and £1·68 per K.W. installed. This figure, however, is certainly on the low side.

Small *versus* Large Power Houses.—The old policy of building small power houses has now given place to concentration of plant, involving the use of larger boiler units and larger steam generators, with a resultant lower capital cost per unit of plant installed and a more economical cost of production per unit of energy delivered.

The average pre-war cost of power house buildings in large cities was from £6 to £11 per K.W. installed; in smaller provincial towns from £3·5 to £6 per K.W.; and for larger power houses outside cities from £2·5 to £3 per K.W. The cost will obviously vary according to the country and the locality.

Generally speaking, the cost of plain, substantial buildings may, for estimating purposes, be reckoned approximately as follows:—

TABLE XI.

FOR ESTIMATING THE COST OF BUILDINGS.

Size of power house.	Pre-war cost of buildings.
K.W. installed.	£ per K.W.
2,500	5·00
5,000	4·00
10,000	3·25
25,000	2·75
50,000	2·50
100,000	2·33

Cable Subways.—In certain power houses whence there are large numbers of cables radiating, it is sometimes necessary and cheaper to build a subway, with side racks.

The subway shown in Fig. 3 is 940 yards long and 10 feet high by 5 feet wide, and built of 18-inch brickwork, with 4 feet of cover between the crown of the arch and the road surface. The approximate cost of the excavation, brickwork complete, cable racks, and reinstatement, was £27·3 per lineal yard.

Repair Workshops.—A repair workshop is a necessary equipment in a power house, and should be handy to the engine-room. The equipment shown in plan in Fig. 4 may be taken as typical. The following tools will usually suffice, viz.:—

(*a*) One 21-inch upright drilling machine, with four speeds, foot-operated striking gear, and three union chucks.

(*b*) One shaping machine.

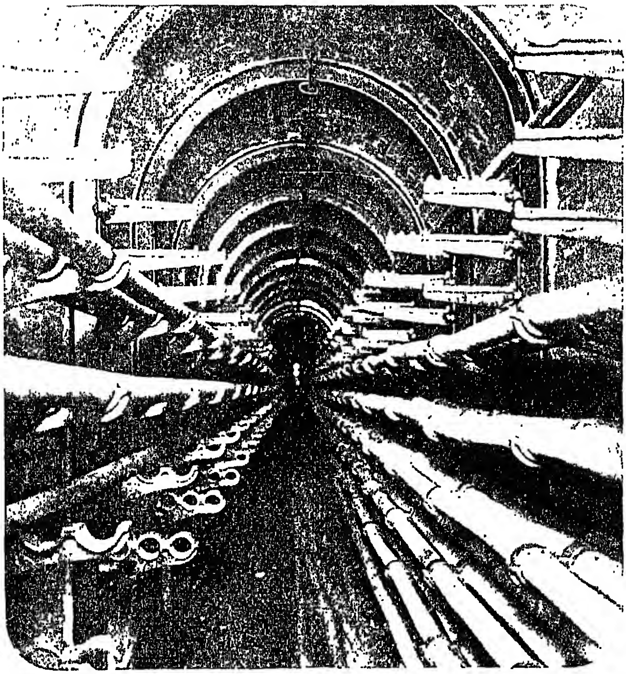

Fig. 3.

(*c*) One suitable gap-bed self-acting lathe, with hand-feed adjustment gear, micrometer adjustment to surfacing screw, complete with change wheels, chucks, hollow spindle, etc.

(*d*) Screwing machine with quick releasing dies.

(*e*) Eight-inch gap lathe.

(*f*) Small brass-finisher's lathe.

(*g*) Bench disc grinder, fitted with steel emery wheel and solid emery wheel, with table and other accessories.

(*h*) 36-inch by 8-inch grindstone, complete with details.

(*i*) Portable screwing machine, with dies to take up to, say, 4-inch pipes.

(*j*) 12-ton jacks with run-out of 12 inches.

(*k*) Ten-ton jacks as may be required.

(*l*) Double-purchase hoisting crabs to lift 5 or 3 tons are sometimes required in distant places.

(*m*) Self-sustaining $7\frac{1}{2}$ tons pulley block, tested to 11 tons, with chains and some smaller blocks if necessary.

(*n*) Set of stocks and dies.

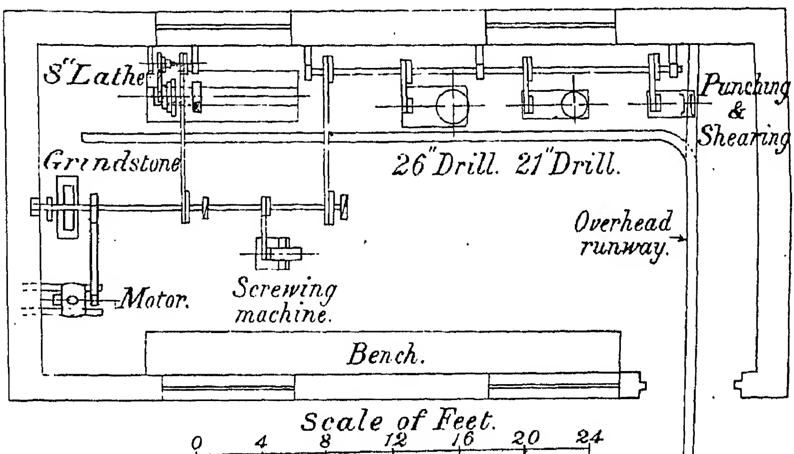

FIG. 4.

(*o*) Surface plate.

(*p*) Bench fitted with vices.

Spare Gear Room.—The buildings should contain a spare gear room, on the walls of which spare parts of all the plant can be hung; or the smaller parts can be arranged on shelves, as in an ordinary factory stores. By arranging these systematically a stock of spare parts can be more easily controlled, and thus spares kept ready to hand out when emergencies arise. Such parts as spare gauge glasses, valves of each kind, packing rings, turbine blades, piston rings, brasses, stator coils, brushes, insulators, instruments, and oil break switches, to mention only a

few, are then always to hand. In remote situations it is well to construct a drying-room for high tension coils, etc.

Oil should be kept in special tanks in an annexe to the main building, and such inflammable stores as waste and rags should be kept apart.

Other Offices.—The superintendent engineer's office should be arranged in a convenient position, so as to be easily accessible and comfortable, and not placed in a hot and ill-ventilated situation. Usually it is placed so as to give a commanding view of the engine-room. Telephonic communication (in a large plant) should be arranged between this office and the boiler houses, engine-room (at several points), and operating switchboard respectively. Separate mess-rooms, lavatories, and bathrooms should be provided for the engine-room and boiler-house staff respectively.

Telephonic and Telegraphic Communication.—An arrangement of electrical signals should be installed between the control switchboard and each turbine, and indicators or telephones between the switchboard and the boiler houses. In some cases the speed of the steam sets is directly controlled from the switchboard gallery by means of reversible motor control.

Travelling Cranes.—These may be conveniently considered here as a part of the building equipment. In the engine-room a travelling crane should be provided of sufficient size to take the maximum load represented by the heaviest piece of machinery required to be handled, such as the bedplate of an engine, an alternator frame, or condenser body. In large power houses, say above 5000 K.W.; the crane should always be motor driven, but in small power houses it is usually hand operated.

The main engine-room crane will command all the engine-room equipment including the condensing plant. Should the design of the power house be such that the condensers are housed in a separate bay, then a smaller crane must also be fixed in that annexe.

The workshop should also be provided with a small travelling crane arranged so as to pick up machinery delivered by the main engine-room crane.

Single girder cranes require least head-room, and are useful

in workshops, or over economisers and such like places where small weights are handled. The lifting gear travels in the bottom flange of the cross girder.

Hand-operated cranes in engine-rooms are usually of the double girder type, which will, of course, take heavier lifts. They also allow the crab operating chains to be carried further away from the centre of the load, with a minimum head space and a capability of lifting as near as possible to the sides of the building.

Care must be exercised in fixing the level of the crane rails so that the largest piece to be installed in the engine-room can be lifted clear of the other machines. Difficulties have often arisen from neglect of this consideration.

Electrically Operated Cranes.—For the larger power houses, electrically operated cranes are advisable. These can be arranged (*a*) for electric lifting only, the cross traverse and main travel being hand operated; (*b*) for electric lifting and main travel, the cross traverse being hand operated; or (*c*) for complete electrical operation either from a cage on the crane or from the floor. They are fitted with overwinding switches, so that the current is automatically cut off from the hoisting motor when the hook has risen to a predetermined height.

For cranes up to a capacity of 25 tons, an efficient unit would consist of a single-motor power hoisting crane with hand-power main travel and cross traverse motions, the axles of these hand-operated motions being fitted with roller bearings so as to reduce the tractive effort to a minimum.

When electrically operated cranes are adopted, the motors may be driven either from a low-tension 3-phase supply or from the auxiliary exciter direct-current sets, whichever may be found more convenient. Some designers prefer to drive all the auxiliary motors in a station from the 3-phase main supply through step-down transformers; others prefer to keep these motors more independent of the main supply by driving them from the exciter circuit. Preference should, however, in the Author's opinion, be given to the former method.

Cranes should always be proof tested to 50 per cent. in excess of full load.

The capacities, leading dimensions, speeds and weights of standard electrically operated cranes manufactured by Messrs.

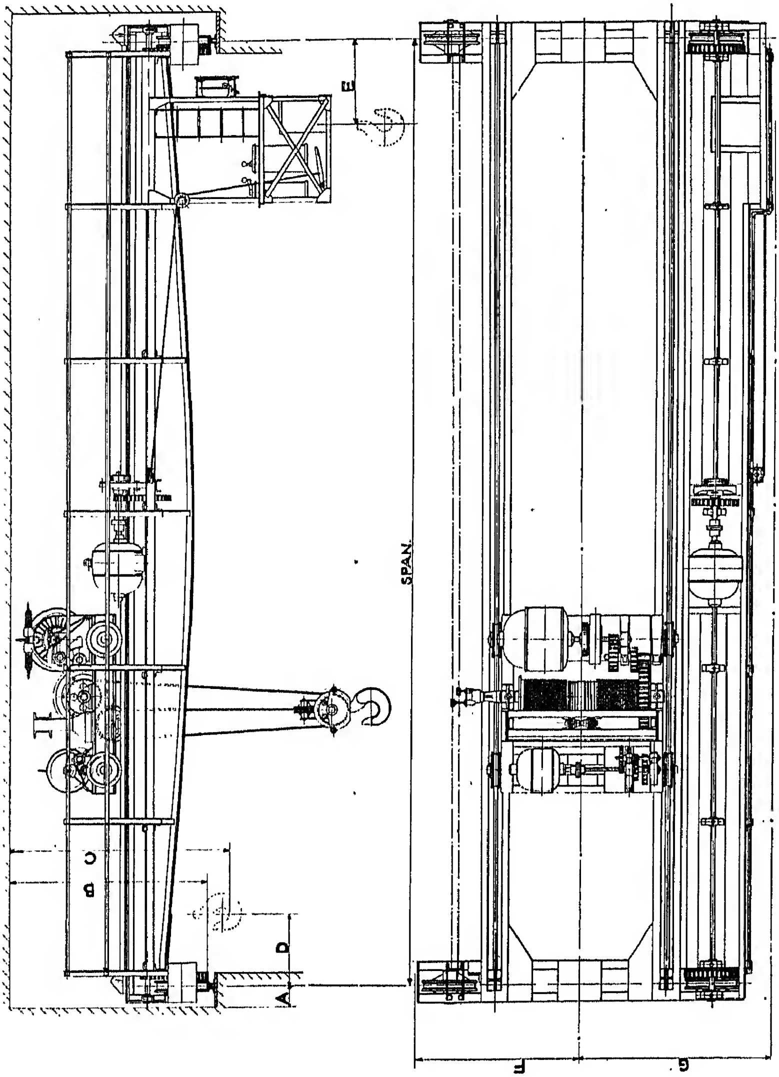

Fig. 5.—Overhead Electric Cranes: Dimensional Diagram.

Herbert Morris, Limited, Loughborough, England, are as indicated in the dimensional drawing (Fig. 5) and in Tables Nos. XII. and XIII.

TABLE XII.

ELECTRIC OVERHEAD TRAVELLING CRANES. (CAPACITIES, SPEEDS, AND DIMENSIONS.)

Capacity (in tons).		1	3	5	10	15	20	30	40	50
Full load speeds (in ft. per min.).	Hoist.	30	25	20	15	10	8	7	6	5
	Traverse.	75	75	65	65	60	60	60	55	55
	Travel.	200	200	175	175	150	150	150	120	120
Span and Leading Dimensions (see Fig. 5).		ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft in.
20 ft. span.	A	7½	8	8	9	10	10	11	11	1 0
	B	4 6	4 9	5 0	6 3	6 3	6 4	7 6	7 9	8 0
	C	4 9	5 0	5 3	6 6	7 9	8 6	9 9	10 3	11 0
	D	2 0	2 3	3 0	3 3	3 3	3 6	3 6	3 9	4 0
	E	2 6	2 9	3 6	4 3	4 6	4 6	4 9	4 9	5 0
	F	4 6	5 3	5 3	5 9	5 9	6 0	6 3	6 6	6 9
	G	5 0	6 0	6 3	6 6	6 6	6 9	6 9	7 0	7 3
30 ft. span.	A	7½	8	8	9	10	10	11	11	1 0
	B	4 6	5 0	5 6	6 3	6 3	6 4	7 6	7 9	8 0
	C	4 9	5 0	5 3	6 6	7 9	8 6	9 9	10 3	11 0
	D	2 0	2 3	3 0	3 3	3 3	3 6	3 6	3 9	4 0
	E	2 6	2 9	3 6	4 3	4 6	4 6	4 9	4 9	5 0
	F	4 6	5 3	5 3	5 9	5 9	6 0	6 3	6 6	6 9
	G	5 0	6 0	6 3	6 6	6 6	6 9	6 9	7 0	7 3
40 ft. span.	A	8	8	9	9	10	10	11	11	1 0
	B	5 3	5 6	5 9	6 6	6 6	6 9	7 6	7 9	8 0
	C	4 9	5 0	5 3	6 6	7 9	8 6	9 9	10 3	11 0
	D	2 0	2 3	3 0	3 3	3 3	3 6	3 6	3 9	4 0
	E	2 6	2 9	3 6	4 3	4 6	4 6	4 9	4 9	5 0
	F	5 3	5 3	5 6	5 9	5 9	6 0	6 3	6 6	6 9
	G	5 9	6 0	6 3	6 6	6 6	6 9	6 9	7 0	7 3
50 ft. span.	A	8	8	9	9	10	10	11	11	1 1
	B	5 3	5 6	5 9	6 6	6 6	6 9	7 6	8 0	8 6
	C	4 9	5 0	5 3	6 6	7 9	8 6	9 9	10 3	11 0
	D	2 0	2 3	3 0	3 3	3 3	3 6	3 6	3 9	4 0
	E	2 6	2 9	3 6	4 3	4 6	4 6	4 9	4 9	5 0
	F	5 9	6 0	6 3	6 3	6 3	6 3	6 3	6 6	7 0
	G	6 3	6 3	6 3	6 9	6 9	6 9	7 3	7 3	7 6
60 ft. span.	A	8	8	9	9	10	10	11	1 0	1 1
	B	5 3	5 6	6 0	6 9	6 9	7 0	8 0	8 3	8 9
	C	4 9	5 0	5 3	6 6	7 9	8 6	9 9	10 3	11 0
	D	2 0	2 3	3 0	3 3	3 3	3 6	3 6	3 9	4 0
	E	2 6	2 9	3 6	4 3	4 6	4 6	4 9	4 9	5 0
	F	6 6	6 6	6 6	7 0	7 3	7 3	7 3	7 6	7.6
	G	6 6	6 6	6 6	7 0	7 6	7 6	7 9	7 9	8 0

TABLE XIII.

ELECTRIC OVERHEAD TRAVELLING CRANES. (CAPACITIES AND APPROXIMATE WEIGHTS.)

Capacity (in tons).			1	3	5	10	15	20	30	40	50
Span and approximate weights. X = Total weight, Y = Heaviest piece, in tons.	20 ft. span.	X	4	5	5¾	8	10	12½	16½	20	23½
		Y	1¼	1½	2¼	3¾	4½	5	6¾	8½	10
	30 ft. span.	X	5	6½	7	10	12½	15	19	23	26½
		Y	1¼	1½	2¼	3¾	4½	5	6¾	8½	10
	40 ft. span.	X	7	8	10	12½	15	18	22	26	30
		Y	*1½	*2	*2½	3¾	4½	5	6¾	8½	10
	50 ft. span.	X	8¾	10¾	12	15	18	21	26	30	34
		Y	*2½	*2¾	*3¼	3¾	4½	5¼	6¾	8½	10
	60 ft. span.	X	10	12½	14½	18	21	24½	30½	35	39
		Y	*3¼	*3½	*4¼	*4¾	*5½	*6½	*8½	*9¼	10

NOTE.—Where marked * the heaviest piece is one of the cross girders. In all other instances the heaviest piece is the case which contains the crab.

Costs of Overhead Travelling Cranes.—Before the war the cost of cranes was approximately as follows :—

Hand-operated :	10-ton capacity	. .	£8 per foot main span.
Ditto :	30-ton ,,	. .	£10 ,, ,, ,, ,,
Electrically operated :	30-ton ,,	. .	£20 ,, ,, ,, ,,

Under present-day conditions in Great Britain (1920), the above figures have increased to about £20, £35, and £80 respectively, the last figure applying to an electrically operated 30-ton crane of the 3-motor type.

Brick Chimneys.—Since large brick chimneys may be deemed an integral part of a building and properly a part of an architect's work, they are dealt with under this section in preference to that on steam-raising plant.

Mention is made of brick chimneys since they are usually necessary in intra-mural power houses. Outside power houses are now more usually equipped with short steel stacks and forced

or induced draught. Particulars of steel stacks and data for the internal areas and heights of chimneys with various sizes of boiler plant are given in the chapter on steam-raising plant.

Chimneys must be erected on firm foundations so as to prevent unequal settlement. The inside surfaces should be smooth so as to reduce the resistance to the flow of gases. Fig. 6 shows a typical brick chimney constructed to the Author's design. The principal dimensions of this shaft are: height 132 feet and sectional area at cap 50 square feet. The chimney is hexagonal on a square plinth. It is customary to specify that in building such a shaft the brickwork shall be carried up regularly, but that when the work has reached ground level an interval of one week is to elapse before the work is proceeded with. Similar rests are given after the first 50 feet of brickwork and each subsequent 25 feet have been built up. Ventilating bricks, usually 14 × 10 inches, are built in the outer walls, with openings connecting the space between the firebrick lining and outer walls, so as to average the temperature and to prevent undue expansion on the stock brickwork. The firebrick lining is usually carried up for a height of 40 or 50 feet.

The batter varies from $\frac{1}{16}$ inch to $\frac{1}{4}$ inch per foot on each side. For small shafts the thickness of brickwork is 9 inches, or one brick, for 25 feet downwards from the cap, increasing by half a brick or $4\frac{1}{2}$ inches for each further 25 feet downwards. For large chimney shafts, i.e. those exceeding 5 feet in internal diameter, the top 25-foot section should be $1\frac{1}{2}$ bricks or 14 inches thick, increasing by half a brick in each 25-foot section downwards as before. A heavy stone cap is always fixed so as to consolidate and bind the structure and also to act as a weather guard.

The cap stones of large shafts are usually arranged as shown in Fig. 6, each stone being bedded and set in cement mortar, and secured to its adjacent stones by copper dovetailed dowels some 9 × 4 × 1 inches sunk into the stones and sealed in with lead. The vertical joints of the capping are arranged so as to break joint with the next course.

Elaborate and costly shafts for power houses are becoming

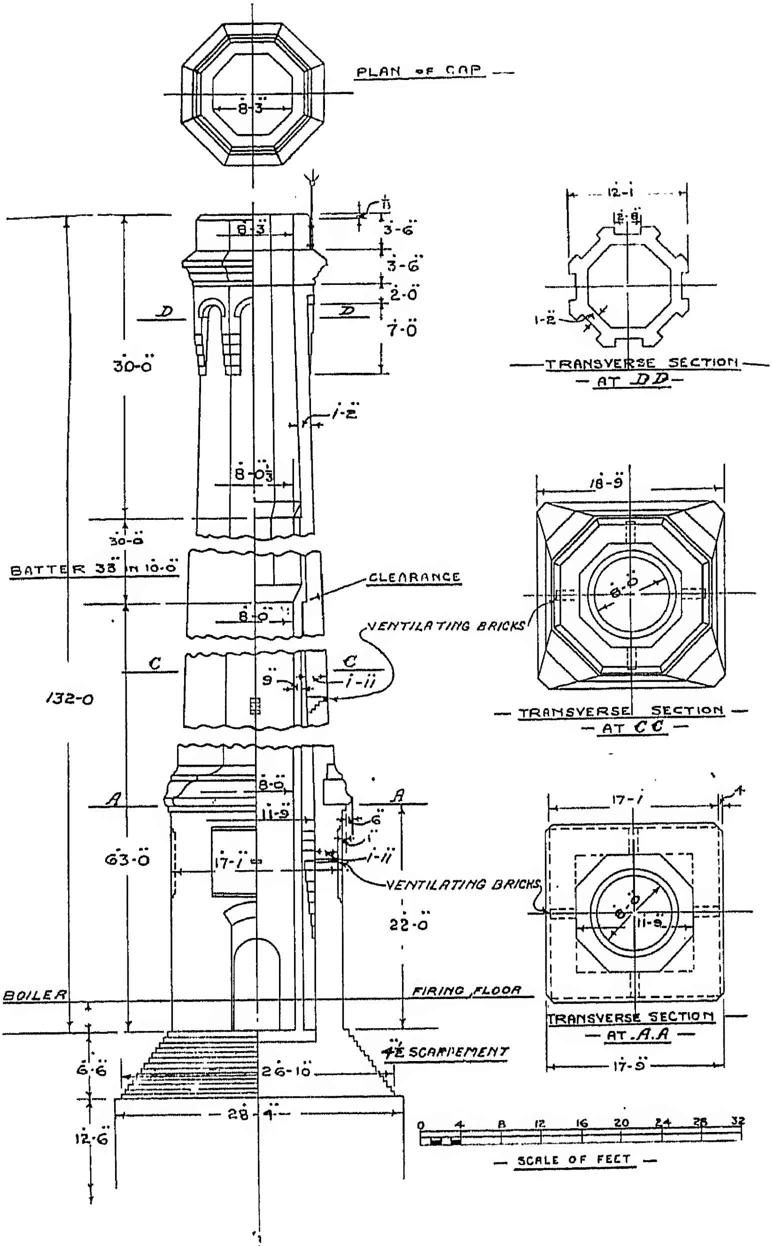
PLAN OF CAP
TRANSVERSE SECTION AT DD
VENTILATING BRICKS
CLEARANCE
TRANSVERSE SECTION AT CC
TRANSVERSE SECTION AT A.A
BATTER 3⅜ IN 10-0
BOILER
FIRING FLOOR
4½ SCARPEMENT
SCALE OF FEET

FIG. 6.

rarer, and it is much better practice wherever possible to adopt a smaller shaft with artificial draught.

The following Table (No. XIV.) gives the general dimensions for various brick chimneys :—

TABLE XIV.

DIMENSIONS OF BRICK CHIMNEYS.

Height of shaft above grate level.	Approximate power natural draught. External air, 68° F.; heated column, 600° F.	Internal dimensions. Base at ground level.	Internal dimensions. At cap. d. = diam. s. = square.	Thickness of walls. Ground level.	Thickness of walls. Cap.	Internal area ratio (bottom to top).
ft.	inches of water.	ft. ins.	ft. ins.	inches.	inches.	
100	0·70	4 8	3 0 (d.)	28	9	2·4
120	0·84	5 6	3 6 (d.)	28	9	2·4
160	1·12	9 0	5 0 (s.)	36	14	3·24
180	1·26	6 4	4 6 (d.)	54	14	2·00
200	1·40	5 3	3 6 (d.)	36	14	2·28
225	1·575	16 0	6 6 (s.)	36	14	4·00
250	1·75	19 0	13 0 (d.)	40	14	2·13

Weight of Brick Chimneys.—The weight of brick shafts of given height and width necessary to withstand the pressure of the wind may be found approximately from the following formula (Hutton) :—

$$W = \frac{H^2 \times b}{B} \times P$$

where W = total weight of shaft, in lbs.,
H = height from base, in feet,
B = external width of shaft at base, in feet,
b = mean external width of shaft, in feet,
P = maximum wind pressure, say, 60 lbs. per sq. ft.

As the weight of built brickwork averages 112 lbs. per cubic foot, the mean thickness of such a chimney in feet, if square, would be

$$\frac{W}{H \times b \times 448}$$

For hexagonal chimneys, multiply the above results by 0·75
For octagonal ,, ,, ,, ,, ,, 0·65
For circular ,, ,, ,, ,, ,, 0·55

Area of Chimneys.—The internal area at the cap of any shaft can be found from the following formula :—

$$A = \frac{W \times G \times C}{\sqrt{H}}$$

where A = internal area at cap in square feet,

W = pounds of fuel consumed per square foot of grate per hour,

G = total grate area of the boiler or boilers in square feet,

H = height of shaft above grate level, in feet,

C = a multiplier for various ranges of boilers ; the values of C being 1 for one boiler, 0·85 for a battery of 2-6 boilers, and 0·75 for a battery of 7-12 boilers.

From the above formula the size of any shaft can be determined, taking care to give the highest probable value to W which is likely to occur in practice.

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DEPARTMENT OF POWER ENGINEERING

CHAPTER IV

STEAM-RAISING PLANT

Boilers.—The selection of the type and size of boilers must depend largely on the size of the turbines or engines to be used, the space available, and on the geographical position of the particular power house.

The two available types are the drum or fire-tube boiler and the water-tube boiler. The drum type may be used with good efficiency for small units in conjunction with an economiser of liberal size, and especially in the case of certain lower load factors on account of its large storage capacity both for water and for steam. This type, however, is much restricted as regards steam pressure and output and it can only be adopted for very small installations. The water-tube boiler has a steam-raising capacity several times greater than that of the drum type per unit of area and volume, and remains the only available type for power houses with larger units of plant. For export work and in situations where the transport of minimum weights is necessary, a sectional water-tube boiler is indispensable.

Drum boilers are generally of the Lancashire two-furnace type, with or without cross circulating tubes, or of the special "Galloway" type, or of the so-called "dry back marine" type. Water-tube boilers are either of the semi-horizontal type, e.g. the Babcock & Wilcox, with the tubes inclined at an angle of 15° from the horizontal; or of the vertical type, e.g. Stirling, with the tubes more or less vertical. Water-tube boilers may also have straight tubes, as in the former type, or bent tubes, as in the latter.

This is not a treatise on boilers and their construction, so the designer must be left to make his choice of the specific type for his requirements. The question here is a broader one of

principle rather than of the details of any particular plant, and the designer must fully weigh the pros and cons in each particular instance. Broadly speaking, the Author thinks there is much to be said in favour of the straight-tube sectional boiler as regards inspection, cleaning, and renewal of tubes, always provided the particular type allows free circulation and gives a high thermal efficiency.

Choice of Type.—Certain data are necessary to determine the best type of boiler for specific cases, namely :—

(1) Size of steam engine or turbine and steam consumption per K.W.H.

(2) Quality of feed water, or "make up" feed water, available.

(3) Qualities of fuel available and the commercially cheapest kind to be used.

(4) Estimated daily average load factor of power house.

(5) Available site, and accessibility for transport of materials.

Taking these points in order :—

The following Table, No. XV., gives the approximate output per boiler and the limiting size of each well-known class, both for condensing power plant, which is more usually installed, and also for non-condensing plant. The steam consumption of the turbine or engine is taken at the normal figures obtainable with any high-class plant.

TABLE XV.

OUTPUT AND LIMITING SIZES OF BOILERS.

Type of boiler.	Limiting output with turbines (condensing.)	Limiting output with reciprocating engines.		Space occupied. (Turbine rating.)	
		(Condensing.)	(Non-condensing).	Per K.W.	Per H.P.
	H.P.	H.P.	H.P.	sq. ft.	sq. ft.
Water-tube	6250	2000	—	0·22	0·17
Dryback marine	715	625	500	0·70	0·56
Lancashire	715	625	500	0 85	0·68

This table (as well as Table No. XVI.) shows that there is a distinct limit to the adoption of drum-type boilers, and that in

cases of power houses with units of plant each exceeding 1000 K.W. output they become prohibitive on account of the space occupied and the increased cost of buildings and pipe work and attendance.

The dry-back marine type requires about 34 square feet of floor space and cost about £100 per 1000 lbs. evaporated per hour at normal rating. The Lancashire type requires about 37 square feet floor space and cost about £100 (with requisite economiser) per 1000 lbs. evaporated per hour at normal rating. The water-tube boiler requires 18 square feet of floor space and cost about £75 per 1000 lbs. evaporated per hour at normal rating: or £102 complete with super-heater and mechanical stokers. In each case the cost is a pre-war figure.

Drum Type Boilers.—The following Table, No. XVI., sets out the standard sizes of Lancashire type boilers:—

TABLE XVI.

STANDARD LANCASHIRE BOILERS.

Size of boiler.		Weight of boiler for the following steam pressures.		Weight of boiler fit-tings.	Heating surface.	Grate area.	Chimney height.	Coal consumption per hour.		Total steam per hour.
Length.	Dia-meter.	120 lbs.	180 lbs.					Per sq. foot of grate area.	Total.	
ft.	ft.	tons.	tons.	tons.	sq. ft.	sq. ft.	ft.	lbs.	lbs.	lbs.
22	6·5	11·25	15·0	3·0	570	25	100	20	500	4,000
24	6·5	12·0	15·75	3·0	620	27·5	100	20	550	4,400
24	7·0	14·0	18·0	3·5	680	29·75	120	24	700	5,600
26	7·0	14·75	19·0	3·5	740	32	120	24	770	6,160
28	7·0	15·75	20·0	—	800	32	130	25	800	6,400
30	7·0	16·75	21·0	—	860	32	140	26	830	6,640
28	7·5	16·5	22·0	4·0	870	35	150	28	980	7,840
30	7·5	17·75	23·0	4·0	930	35	165	30	1050	8,400
30	8·0	20·25	27·0	—	1000	38	180	32	1220	9,760
30	8·5	23·0	30·0	4·5	1050	40	185	33	1320	10,560
30	9·0	25·0	34·0	4·5	1120	43	200	35	1500	12,000

NOTE.—The above evaporative capacities are for a good quality of coal (of about 13,500 to 14,000 B.Th.U.), and assuming the boiler to be fitted with economisers of adequate and properly proportioned heating surface.

The Galloway boiler has about 10 per cent. more heating surface than the plain Lancashire type as above, with consequent higher efficiency and higher evaporative capacity than the figures given in Table No. XVI.

Or consider next the dryback marine type, which is doing excellent work in many smaller stations. This type, on account of its larger heating surface per unit volume of drum, has a consequent higher evaporative duty and a larger capacity in H.P. per square foot of space occupied. These boilers, too, are less unwieldy than the larger plain drum type. Owing to their greater diameter, shorter drums, and higher duty, they are more available for simple designs with larger units of plant than the plain drum type, and they can be better laid out in double rows.

Both classes of drum boiler possess the great disadvantage of difficulty of transport owing to the large dimensions of the drums and their total weights. Again, under emergency, neither class can be forced without running the risk of damage to furnaces or tube plates, and of incomplete and wasteful combustion. With boilers of this construction working at normal rates of evaporation, an economiser must be added, and is essential if the heat contained in the fuel is to be properly utilized.

Water-tube Boilers.—In all larger power houses water-tube boilers are obligatory. In fact, for plant units of 1000 K.W. and upwards the water-tube class is indispensable, having regard to economy of space and to good design. The water-tube type, moreover, is safer than the drum, and is used for the now more prevalent higher pressures. Steam can be raised more rapidly, and the boiler can be forced to a high degree of overload, though certain types are given to priming if overloaded too greatly. Being made in sections, none of the individual parts is heavy or too bulky, and the boiler can therefore be easily transported either by land or sea.

Straight Water-tube Boilers.—Without unfairness to other makers, it may be said that the Babcock & Wilcox boiler typifies the straight-tube class and is best known. This boiler is specially designed for easy transport *per mare et terram* and for easy erection. The one disability it possesses is the large number of caps required to close the tubes, which need to be removed

TABLE XVII.

STANDARD SIZES OF BABCOCK & WILCOX BOILERS. (W.I.F. Types.)

Heating surface.	Evaporation per hour. (Actual.)	Construction.						Furnace.	Approximate total weight. (Packed.)	Space occupied.			
		Tubes.			Drums.					Single boiler.			Two boilers in battery.
										Over brick-work.		Height when hand fired.	
		Wide.	High.	Long.	No.	Diam.	Long.	Area.		Length.	Width.		Width.
sq. ft.	lbs.					in.	ft. in.	sq. ft.	tons.	ft. in.	ft. in.	ft. in.	ft. in.
119	360	3	4	6	1	24	10 5	5·20	3¾	9 6 ×	4 5 ×	10 5⅛	8 0
150	460	3	4	8	1	24	12 6	6·25	4½	11 6 ×	4 5 ×	10 5⅛	8 0
181	520	3	5	8	1	24	12 6	7·23	5	11 6 ×	4 5 ×	10 11⅛	8 0
219	660	3	5	10	1	24	14 9	8·33	5¼	13 6 ×	4 5 ×	10 11⅛	8 0
293	890	4	5	10	1	30	15 0	10·64	6	13 6 ×	5 0 ×	11 5⅛	9 2
343	1,050	4	5	12	1	30	17 0	10·64	6¼	15 6 ×	5 0 ×	11 5⅛	9 2
401	1,200	4	6	12	1	30	17 7	11·97	6½	16 0 ×	5 8 ×	12 5⅝	9 10
460	1,380	4	6	14	1	30	19 9	13·30	7¼	19 0 ×	5 8 ×	12 5⅝	9 10
526	1,600	4	7	14	1	30	19 9	13·30	7¾	19 0 ×	5 8 ×	12 11⅝	9 10
593	1,800	4	8	14	1	30	19 9	13·30	8	19 0 ×	5 8 ×	13 5⅝	9 10
735	2,250	5	8	14	1	36	19 10	16·25	9¼	19 0 ×	6 3 ×	13 11¾	11 0
870	2.650	6	7	16	1	36	21 11	19·15	11¼	21 0 ×	6 10 ×	13 5¾	12 2
983	3,000	6	8	16	1	36	21 11	19·15	12	21 0 ×	6 10 ×	14 1	12 2
1098	3,350	6	9	16	1	36	21 11	23·00	12¾	21 0 ×	6 10 ×	14 7	12 2
1218	3,700	6	9	18	1	36	23 10	23·00	13½	23 0 ×	6 10 ×	15 1	12 2
1265	3,850	7	8	18	1	36	23 10	26·50	14½	23 0 ×	7 5 ×	14 7	13 4
1411	4,300	7	9	18	1	36	23 10	26·50	15¼	23 0 ×	7 5 ×	15 1	13 4
1426	4,350	7	9	18	1	42	24 1	26·50	15¾	23 0 ×	7 5 ×	15 7	13 4
1619	4,900	8	9	18	1	42	24 1	30·00	16¼	23 0 ×	8 0 ×	15 7¾	14 6
* 1741	5,300	12	7	16	2	36	21 11	36·65	20¼	21 0 ×	10 4 ×	15 0¼	19 2
1790	5,400	8	10	18	1	42	24 1	35·00	17¾	23 0 ×	8 0 ×	16 1¾	14 6
1827	5,600	9	9	18	1	48	24 3	33·50	18¾	23 0 ×	8 7 ×	16 1⅞	15 8
* 1966	6,000	12	8	16	2	36	21 11	36·65	21	21 0 ×	10 4 ×	15 6¼	19 2
2010	6,100	9	10	18	1	48	24 3	39·00	21¼	23 0 ×	8 7 ×	16 7⅞	15 8
* 2197	6,700	12	9	16	2	36	21 11	44·00	22¼	21 0 ×	10 4 ×	16 0¼	19 2
2255	6,800	10	10	18	1	54	24 5	43·00	22¾	23 0 ×	9 2 ×	17 3⅛	16 10
* 2437	7,400	12	9	18	2	36	23 10	44 00	24¼	23 0 ×	10 4 ×	16 1½	19 2
* 2531	7,700	14	8	18	2	36	23 10	51·00	27	23 0 ×	11 6 ×	15 7½	21 6
* 2690	8,200	12	10	18	2	36	23 10	51·00	25¼	23 0 ×	10 4 ×	16 7½	19 2
* 2823	8,600	14	9	18	2	36	23 10	51·00	27¾	23 0 ×	11 6 ×	16 1½	21 6
* 2852	8,700	14	9	18	2	42	24 1	51·00	28¼	23 0 ×	11 6 ×	16 9⅜	21 6
* 3140	9,600	14	10	18	2	42	24 1	59·50	29½	23 0 ×	11 6 ×	17 3⅜	21 6
* 3240	9.900	16	9	18	2	42	24 1	58·00	30	23 0 ×	12 8 ×	16 9⅜	23 10
* 3580	11,000	16	10	18	2	42	24 1	67·50	31¼	23 0 ×	12 8 ×	17 3⅜	23 10
* 3654	11,200	18	9	18	2	48	24 3	65·00	35¼	23 0 ×	13 10 ×	17 4¾	26 2
* 4020	12,300	18	10	18	2	48	24 3	76·00	37¼	23 0 ×	13 10 ×	17 10¾	26 2
* 4510	3,800	20	10	18	2	54	24 5	84·00	44½	23 0 ×	15 0 ×	18 2⅞	28 6
* 4789	14,600	18	12	18	2	48	24 3	96·00	41¼	23 0 ×	13 10 ×	18 8⅞	26 2
* 5346	16,000	20	12	18	2	54	24 5	106·00	48	23 0 ×	15 0 ×	20 2⅞	28 6
* 5540	17,000	18	14	18	2	48	24 9	106·00	46¼	23 6 ×	13 10 ×	18 9⅞	26 2
* 6182	19,000	20	14	18	2	54	24 11	120·00	53¼	23 6 ×	15 0 ×	20 2⅞	28 6
† 6328	19,400	24	12	18	3	42	24 7	120·00	54¼	23 6 ×	17 4 ×	19 11⅛	—
† 7135	21,500	27	12	18	3	48	24 9	144·00	63	23 6 ×	19 1 ×	21 5¼	—
† 7322	22,000	24	14	18	3	42	24 10	144·00	60	23 6 ×	17 4 ×	21 11⅛	—
† 8019	24,500	30	12	18	3	54	24 11	156·00	76¼	23 6 ×	20 10 ×	21 11¼	—
† 8283	25,000	27	14	18	3	48	25 0	168·00	69¾	23 6 ×	19 1 ×	22 5¼	—
† 9273	28,000	30	14	18	3	54	25 2	196·00	80¾	23 6 ×	20 10 ×	22 11¼	—

* These boilers have two steam and water drums joined by a wrought steel cross pipe.
† These boilers have three steam and water drums joined by wrought steel cross pipes.
The ten largest sizes are not recommended for hand firing.

occasionally for inspection of tubes and for internal cleaning. On the other hand, by removing these caps, the water tubes may be easily inspected by placing a lamp at one end, and also easily cleaned. The ends of the tubes are expanded by a special taper mandril into the pressed steel header, and thus can also be easily cut out and replaced. In this respect this boiler enjoys an advan-

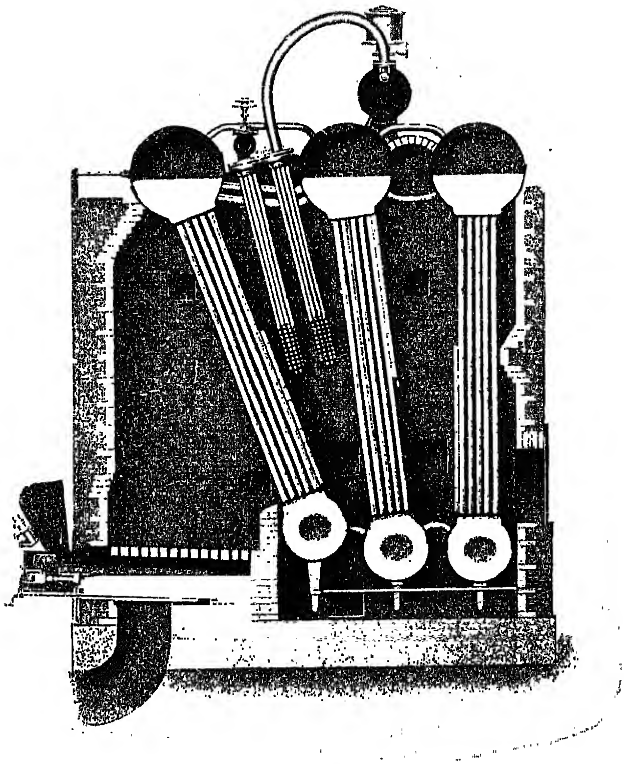


Fig. 7.—Fitted with Underfeed Stoker (with Fan).

tage possessed by no other type. Accumulations of soot on the exterior of the tubes may be removed by a steam hose and jet, for which access is given by small hand-holes built into the side walls of the brickwork setting, or by scrapers, for which access to the tubes must be provided. The latter method is better, and prevents corrosion of the tubes which may arise from the steam jet and accumulated soot.

The leading dimensions, weights, evaporative capacities, and other particulars of standard Babcock & Wilcox boilers are set out in Table No. XVII.

There are other straight-tube types which have given excellent results, such as the Woodeson boiler made by Messrs. Clarke, Chapman & Co. of Gateshead, England. This boiler is

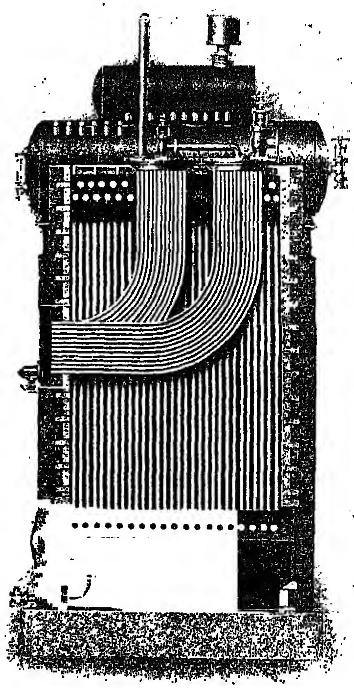


Fig. 8.—Section.

built up of a number of sections, each consisting of a steam drum at the top, a water drum at the bottom, and a number of groups of tubes varying with the size of the boiler. The tubes are expanded into flat discs, which are hydraulically pressed out of the solid plates of both the steam and water drums. Manholes on the steam drums are arranged over each group of tubes, enabling them to be easily inspected or withdrawn and renewed.

Each steam drum is connected to the neighbouring drum by horizontal circulating pipes; and the water drums are connected in a similar manner. The whole boiler is suspended from girders, and is entirely free at the bottom to allow for expansion.

The fire-grate is fixed across the boiler and immediately in front of the tube sections as shown in Figs. 7 and 8. The gases travel upwards through the nests of front tubes, over the fire-brick baffle which is arranged between the sections, and thence downwards through the back sets of tubes to the exit damper. The water circulation is from the rear steam drum, where the feed water enters at a point furthest away from the fire, down the back tubes, and up the front tubes. All deposit is left in the bottom rear drum, and the tubes in the front sections exposed to the greatest heat have thus only clean water circulating in them.

The following Table, No. XVIII., sets out the leading dimensions, weights, and other particulars of the Woodeson boiler, arranged for (A) Underfeed Stokers, and (B) Chain Grate Stokers.

TABLE XVIII.

A.—Woodeson Boilers fitted with Underfeed Stokers.

Evaporation per hour f. and a. 212° Fahr.	Heating surface.	Grate area.	No. of sections.	No. of groups of tubes per section.	Shipping.		Overall Dimensions.		
					Weight.	Measure.	Height.	Width.	Depth.
lbs.	sq. ft.	sq. ft.			tons.	cub. ft.	ft. in.	ft. in.	ft. in.
6,555	1350	23	3	2	23	1610	22 9	6 3	21 0
9,690	2025	34	3	3	29	2000	22 9	7 10	21 0
12,825	2700	45	3	4	33	2310	22 9	9 5	21 0
15,960	3450	56	3	5	37	2590	22 9	11 0	21 0
19,380	4050	68	3	6	44	3080	22 9	12 7	21 0
22,600	4750	79	3	7	50	3500	22 9	14 2	21 0
25,650	5400	90	3	8	55	4140	22 9	15 9	21 0

TABLE XVIII.—*Continued.*

B.—Woodeson Boilers fitted with Chain Grate Stokers.

Evaporation per hour f. and a. 212° Fahr.	Heating surface.	Grate area.	No. of sections.	No. of groups of tubes per section.	Shipping.		Overall dimensions.					
					Weight.	Measure.	Height.		Width.		Depth.	
lbs.	sq. ft.	sq. ft.			tons.	cub. ft.	ft.	in.	ft.	in.	ft.	in.
6,440	1350	28	3	2	27	1710	22	9	6	3	24	0
9,430	2025	41	3	3	36	2260	22	9	7	10	24	0
12,000	2700	52	3	4	41	2570	22	9	9	5	24	0
14,950	3450	65	3	5	48	2950	22	9	11	0	24	0
18,170	4050	79	3	6	53	3200	22	9	12	7	24	0
20,470	4650	89	3	7	62	3790	22	9	14	2	24	0
24,150	5400	105	3	8	69	4200	22	9	15	9	24	0

Bent Water-tube Boilers.—The Stirling boiler typifies the bent tube class of water-tube boiler, and is frequently adopted for power houses. It possesses an advantage over the Babcock type in that the drums are smaller and can be more readily transported to situations up-country which are often difficult of access. It is claimed that, owing to the design of the boiler and to the more vertical inclination of the tubes, freer ebullition is obtained and steaming is easier; also that, owing to the curvature of the tubes, there are less strains on the boiler parts. It is also claimed that less scale can form or lodge in the tubes. On the other hand, good make-up feed water free from scale-forming matter is imperative. Owing to the curvature of the tubes and their smaller diameter they cannot be so easily inspected as the straight types, and there are more tubes for a given heating surface. There are, however, no caps to be ground in, nor special headers required into which the tubes have to be expanded. There are many other types of bent-tube boilers, for each of which special advantages are claimed in respect of details.

The following Table, No. XIX., gives the principal dimensions and particulars of weights, etc., of some standard sizes of Stirling boilers:—

TABLE XIX.

Some Standard Sizes of Stirling Water-tube Boilers.

Heating surface.	Grate area.	Construction. Length over ends. Of steam drums. Single.	Construction. Length over ends. Of steam drums. Battery.	Construction. Length over ends. Of mud drum.	Construction. Main tubes. Wide.	Construction. Main tubes. Deep.	Construction. Main tubes. Total.	Construction. Furnace. Length and width.	Width over brickwork. Single.	Width over brickwork. Battery.
sq. ft.	sq. ft.	ft. in.	ft. in.	ft. in.				ft. in. ft. in.	ft. in.	ft. in.
								Hand fired.		
630	19½	5 9	5 3	4 10	6	13	78	6 6 × 3 0	6 0	11 0
840	26	6 9	6 3	5 10	8	13	104	6 6 × 4 0	7 0	13 0
1050	32½	7 9	7 3	6 10	10	13	130	6 6 × 5 0	8 0	15 0
1365	42¼	9 3	8 9	8 4	13	13	169	6 6 × 6 6	9 6	18 0
1575	48¾	10 3	9 9	9 4	15	13	195	6 6 × 7 6	10 6	20 0
								Single stokers		
1902	55	8 10	8 6	8 2	12	14	168	10 0 × 5 6	9 0	17 3
2220	65	9 10	9 6	9 2	14	14	196	10 0 × 6 6	10 0	19 3
2380	70	10 4	10 0	9 8	15	14	210	10 0 × 7 0	10 6	20 3
2499	60	8 6	8 1	7 4	11	18	198	12 0 × 5 0	8 6	16 3
2946	72	9 6	9 1	8 4	13	18	234	12 0 × 6 0	9 6	18 3
3394	84	11 0	10 7	9 10	16	18	288	12 0 × 7 0	11 0	21 3
4065	96	12 0	11 7	10 10	18	18	324	12 0 × 8 0	12 0	23 3
								Double stokers		
4736	105½	13 6	—	12 4	21	18	378	12 0 × 4 4¾	13 6	—
5183	120	14 6	—	13 4	23	18	414	12 0 × 5 0	14 6	—
6687	132	15 6	—	14 4	25	18	450	12 0 × 5 6	15 6	—
7750	156	17 6	—	16 4	29	18	522	12 0 × 6 6	17 6	—
8548	168	18 6	—	17 4	32	18	576	12 0 × 7 0	19 0	—
9877	192	21 6	—	20 4	37	18	666	12 0 × 8 0 (two)	21 6	—
								Treble stokers		
11473	216	24 6	—	23 4	43	18	774	12 0 × 6 0	24 6	—
12800	246	27 0	—	25 10	48	18	864	{12 0 × 6 6 / 12 0 × 7 0}	27 0	—

Note.—(1) The above-mentioned grate areas can be increased by installing Stokers 14 feet or even 16 feet long.

(2) Stirling boilers are in hand capable of evaporating 100,000 lbs. of water per hour each, and have been designed for evaporations up to 176,000 lbs. of water per hour in one unit.

With regard to the evaporation of Stirling boilers, the normal rate of working may be taken as about 4 lbs. of water

from and at 212° Fahr. per square foot of heating surface per hour. The amount of overload depends on the grate area supplied and the quality of fuel used.

Marine Type Water-tube Boilers.—The latest development in some of the more important power stations where floor space

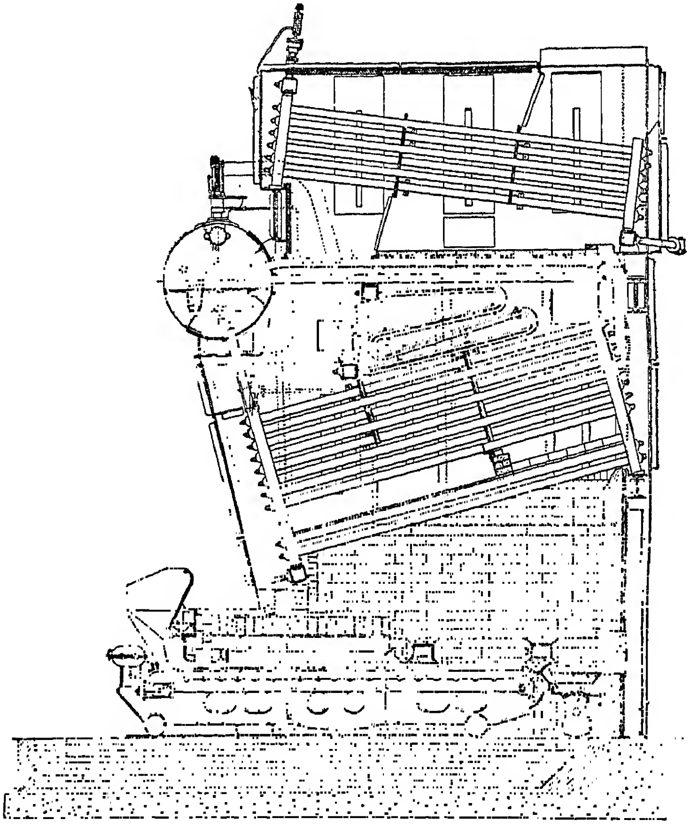


Fig. 9.

is expensive, and where it is desired to install the maximum of power in the minimum of space and with the highest thermal efficiency, is the use of the marine type of water-tube boiler modified to suit land requirements.

The evaporative capacity of every boiler is obviously governed by the amount of grate area provided, for with a given fuel and

a given draught over the furnace, the coal consumption per square foot of grate area is, broadly speaking, a constant. In this respect water-tube boilers have an advantage over the drum type of construction in that the refractory nature of the brick-work lining of their furnaces facilitates combustion, and therefore enables a somewhat greater quantity of coal to be consumed per square foot of grate area.

It follows that a construction of boiler which enables practically the whole of the ground space occupied by it to be utilized for grate area, is that which will give the greatest evaporation per square foot of boiler-house floor.

Fig. 9 shows a Babcock & Wilcox marine type boiler as applied to land purposes. The furnace occupies the whole of the space underneath the tubes, and thus utilizes the ground space to the best advantage.

With this type of construction the boilers are entirely enclosed in an iron casing, which prevents any infiltration of air. There is a structural iron framing surrounding the pressure parts and firmly bolted to the foundations to which the casing plates are fastened. The sides of the furnace are composed of firebricks, the whole of the structure being surrounded by removable iron casings lined with fire-refractory material. Hinged doors at the front and rear permit of access to the handhole fittings, and doors in the side casings enable the ready removal of soot from the exterior of the tubes.

The compact nature of a boiler house equipped with marine type boilers is illustrated by reference to Plate II., which shows the plant installed at Grande Centrale, Buenos Ayres.

The ground spaces occupied by Babcock & Wilcox marine type boilers together with other leading particulars are given in Table No. XX.

Rating of Boilers.—Boilers are rated by their normal evaporation from and at 212° Fahr. or 100° C. The evaporation is dependent upon the amount of heat transmitted through the heating surface of the boiler. In the Babcock marine type of boiler, the average rate of transmission is about 7000 B.Th.U. per hour per square foot of heating surface and the normal evaporation corresponds approximately to this transmission

rate. With ordinary coal having a calorific value of about 12,000 B.Th.U., the rate of coal-burning on the stokers for the normal output is about 22 lbs. per hour per square foot of grate area.

TABLE XX.

MARINE TYPE BOILERS FOR LAND INSTALLATIONS.

Boiler heating surface.	Normal evaporation per hour. (Actual.)	Maximum evaporation per hour for short periods.	Grate area. (Stoker fired.)	Economiser heating surface.	Superheater heating surface.	Ground space occupied. Depth and Width.
sq. ft.	lbs.	lbs.	sq. ft.	sq. ft.	sq. ft.	ft. in. ft. in.
2316	13,800	18,000	84	1197	845	22 6 × 12 11
2482	15,000	19,500	91	1283	888	22 6 × 13 6
2647	16,100	21,000	98	1369	930	22 6 × 14 1
2978	18,400	24,000	112	1540	1057	22 6 × 15 3
3474	20,400	26,500	123·6	1796	1226	22 6 × 17 0
3805	23,100	30,200	140	1967	1353	22 6 × 18 2
4136	25,400	33,000	154	2139	1480	22 6 × 19 4
4467	27,700	36,000	168	2310	1606	22 6 × 20 6
4632	30,000	39,000	182	2395	1649	22 6 × 21 1
4963	32,300	42,000	196	2566	1776	22 6 × 22 3
5294	34,600	45,000	210	2738	1902	22 6 × 23 5
5625	36,900	48,000	224	2909	2029	22 6 × 24 7
6121	38,100	49,500	231	3165	2198	22 6 × 26 4
6618	41,600	54,000	252	3422	2367	22 6 × 28 1
6948	45,000	58,500	273	3593	2494	22 6 × 29 3
7445	48,500	63,000	294	3850	2663	22 6 × 31 0
8272	55,400	72,000	336	4278	2959	22 6 × 33 11

NOTE.—The figures in this Table are baesd upon a steam pressure of 200 lbs. per sq. in., a final steam temperature of 662° Fahr., and a feed temperature into the economiser of 100° Fahr.

Water-tube boilers are capable of being forced considerably above the normal rate of evaporation, and the figures given in Table No. XX. show the capabilities of the marine type under normal and emergency conditions respectively. In the case of the Babcock "Express" type boiler for naval use, fitted with small tubes, evaporations as high as 23 to 24 lbs. of water from and at 212° Fahr. per square foot of heating surface have been obtained with an oil consumption corresponding to about 2 lbs. per square foot of heating surface, the draught required under such conditions being about 5 inches.

The evaporation from any given feed-water temperature can

be easily corrected to the datum line of 212° Fahr. by the following rule :—

If H = total heat in B.Th.U. per lb. of steam at the boiler working pressure from 32° Fahr.,

W = lbs. of water actually evaporated per lb. of fuel,

T = temperature of feed water in degrees Fahr.,

the equivalent evaporation per lb. of fuel from and at 212° Fahr. is given by

$$X = W \times \frac{(H + 32) - T}{966}$$

Conversely, when tables show the rated evaporation of boilers from and at 212° Fahr., as is usual, the same formula may be used to assess the evaporation at any particular temperature.

The diagram in Fig. 10, supplied by Messrs. Babcock & Wilcox, provides a ready means of obtaining equivalent evaporations from and at 212° Fahr. for saturated and superheated steam at various steam pressures and feed water temperatures.

In the case of saturated steam, the right-hand side only of the diagram is used. The intersection of the vertical line of steam pressure with the curved line of feed temperature is followed horizontally to the *right*-hand scale giving the factors for equivalent evaporation.

In the case of superheated steam, the whole of the diagram is employed. The intersection referred to above is followed horizontally to the *left* as far as the division line between the two portions of the diagram. The nearest inclined line is then followed to its intersection with the vertical line of superheat, this intersection being followed horizontally to the *left*-hand scale giving the factors for equivalent evaporation. As the specific heat of superheated steam varies with the pressure, the necessary corrections are given at the bottom of the left-hand side of the diagram for every 20 lbs. pressure above or below 200 lbs. per square inch and for superheats of 100°, 200°, and 300° Fahr.

Boiler Efficiency.—The efficiency of any boiler is given by the ratio of the heat units in the steam generated to the total heat units in the fuel used, and depends on the rate of evaporation per square foot of heating surface. This rate has a critical

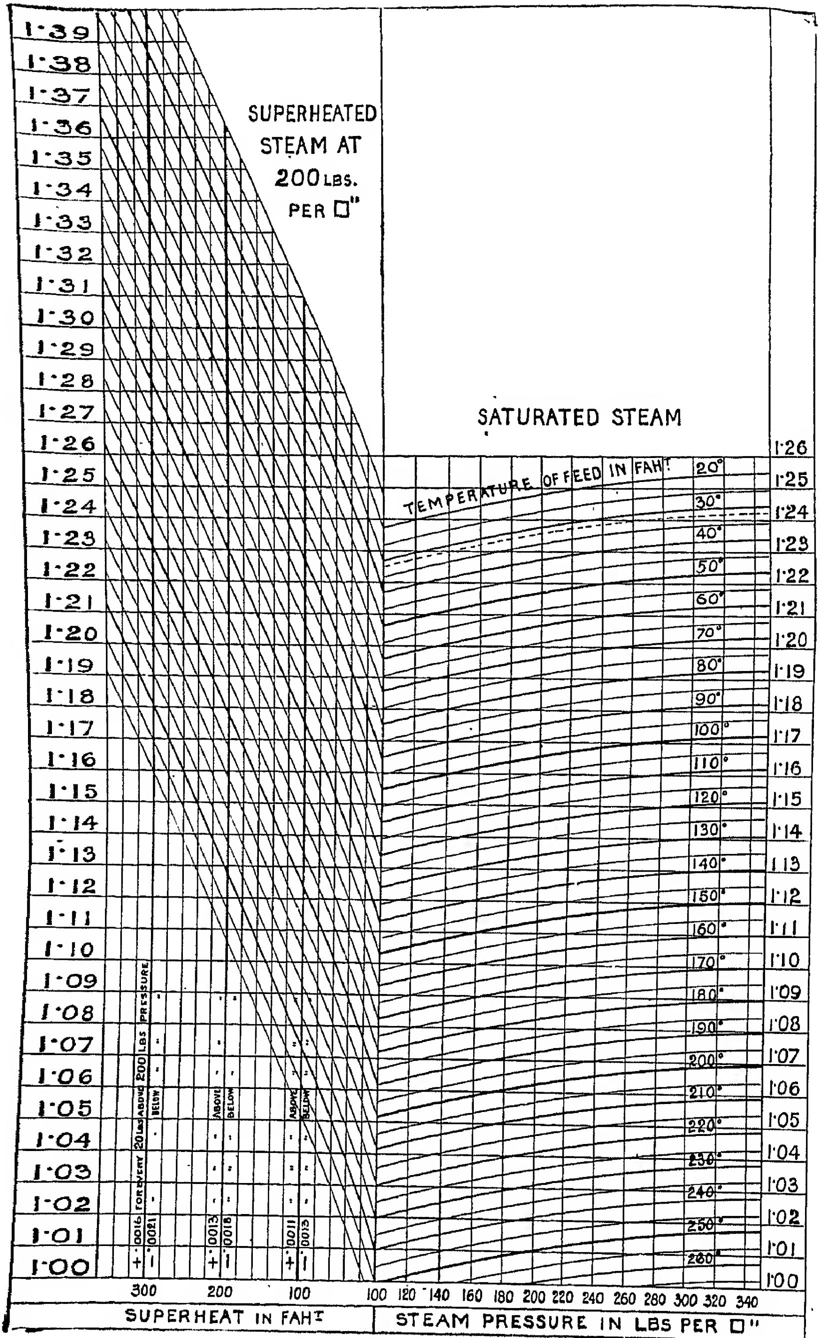

SUPERHEATED STEAM AT 200 LBS. PER □"
SATURATED STEAM
TEMPERATURE OF FEED IN FAHT.
20° 30° 40° 50° 60° 70° 80° 90° 100° 110° 120° 130° 140° 150° 160° 170° 180° 190° 200° 210° 220° 230° 240° 250° 260°
1·39 1·38 1·37 1·36 1·35 1·34 1·33 1·32 1·31 1·30 1·29 1·28 1·27 1·26 1·25 1·24 1·23 1·22 1·21 1·20 1·19 1·18 1·17 1·16 1·15 1·14 1·13 1·12 1·11 1·10 1·09 1·08 1·07 1·06 1·05 1·04 1·03 1·02 1·01 1·00
FOR EVERY 20 LBS ABOVE 200 LBS PRESSURE + ·0016
BELOW − ·0021
ABOVE + ·0013
BELOW − ·0018
ABOVE + ·0011
BELOW − ·0013
300 200 100
100 120 140 160 180 200 220 240 260 280 300 320 340
SUPERHEAT IN FAHT
STEAM PRESSURE IN LBS PER □"

Fig. 10.

value, i.e. the efficiency of any type of boiler will be less if the rate of evaporation be increased beyond or reduced below this critical value.

The efficiency may be impaired through not selecting the most suitable type of boiler for the particular class of fuel available; by selecting a wrong class of mechanical stoker, or through congested flues or inefficient draught; air leakages through badly constructed brick walls, joints, and damper slots, cold feed, and through radiation from the boiler parts. These various matters are treated later, with notes on the means of reducing or overcoming such losses.

Boiler Testing.—Boilers should be tested *in situ* after completion. In addition to the tests of the coal-feeding plant, and ash removal, feed-water supplies, gauges, valves, and blow-down details, air tightness of flues and brickwork, adequacy and variability of draught, there remains the calorific balance, or thermal efficiency of the boiler.

It is usual to specify a certain rated output of steam per boiler, with a guaranteed evaporation from and at 212° Fahr. per lb. of fuel of specified heat value, with a specified consumption of fuel per square foot of grate area at a given draught measured by a water column gauge at the boiler damper. The test should start and finish with water at a fixed level in the gauge, and last over several hours so as to minimize the percentage error due to the possible slight difference in measuring this water-level. The test-sheet shown in Table No. XXI. on p. 64 may be used as a guide.

The following apparatus are necessary to conduct such a test:—

(*a*) Means of weighing coal. A steelyard platform machine, checked against standard weights, is usually provided for weighing out coal in baskets, tubs, or sacks.

(*b*) Means of weighing ash and clinker.

(*c*) Means of weighing the water fed into boiler. Two graduated feed tanks provide the surer method. A water meter of the Venturi pattern may be used as a further check.

TABLE XXI.

Boiler Test-Sheet.

Result of test made at

by on 19 ,

in the presence of

Boiler No.				Furnace. F. No.		Superheater. S. H. No.......		Economiser. E. No.	
Type.	Construction.	Heating surface.	Ratio heating surface to grate area.	Method of firing.	Grate area and dimensions.	Style.	Heating surface.	Type.	Heating surface.

Guarantees.

Summary of results.			No. 1 Test.	No. 2 Test.
Duration		hours	—	—
Fuel	Name and class	—	—	—
	Colliery district and price	—	—	—
	Volatile matter	per cent.	—	—
	Calorific value (dry)	B.Th.U.	—	—
	Percentage moisture	per cent.	—	—
	Total fired (wet)	lbs.	—	—
	,, ,, (dry)	,,	—	—
	Consumed per hour (wet)	,,	—	—
	,, ,, square foot grate per hour (wet)	,,	—	—
	Thickness of fire	ins.	—	—
	Ash by analysis	per cent.	—	—
	,, actual	,,	—	—
Steam	Average pressure	lbs.	—	—
	Saturated temperature	deg. F.	—	—
	Superheated temperature	,,	—	—
	Degree of superheat	,,	—	—
Water	Temperature entering economiser	,,	—	—
	,, ,, boiler	,,	—	—
	Total evaporated, actual	lbs.	—	—
	Per hour, actual	,,	—	—
	,, ,, from and at 212°	,,	—	—
	,, square foot H.S., from and at 212°	,,	—	—
	,, lb. (wet) coal, actual	,,	—	—
	,, ,, (dry) ,, ,,	,,	—	—
	,, ,, (wet) ,, from and at 212°	,,	—	—
	,, ,, (dry) ,, ,, ,, ,,	,,	—	—
	Factor of evaporation (including superheat)	—	—	—
Flue gases	Draught (and kind)	ins.	—	—
	Flue temperature, boiler damper	deg. F.	—	—
	Boiler house temperature	,,	—	—
	CO_2	per cent.	—	—
	CO	,,	—	—
	O	,,	—	—
Efficiency	Boiler with stoker	,,	—	—
	,, and superheater	,,	—	—
	,, superheater, and economiser	,,	—	—

(*d*) Thermometers for measurement of feed-water temperature.
(*e*) Thermometer to measure superheat of steam.
(*f*) Pyrometer, or nitrogen thermometer to measure the temperature of the flue gases leaving the boiler.
(*g*) Pressure gauges for steam.
(*h*) Chemical apparatus for measurement of composition of flue gases. A CO_2 recorder may also be fixed as a guide to the boiler superintendent.
(*i*) Draught gauges at grate and at boiler damper. Water column gauges are most suitable.
(*j*) Chemical apparatus for measurement of calorific value of samples of coal used during testing. When possible, it is better to send samples of the coal to a properly equipped laboratory where a speciality of this class of test is made.

The greatest care must be taken to ensure that the samples taken do fairly represent the bulk of the coal burnt during the test. A shovelful of coal should be taken from each basket or tub weighed out. These samples should be accumulated in a storage tub until the end of the test; they should then be emptied on to a cleanly swept part of the floor of the boiler house, and thoroughly mixed and flattened. Two lines at right angles should be then drawn dividing the coal into quarters. Two opposite quarters are then removed and the remainder again mixed and similarly divided, and so on, until only a few shovelfuls remain. All lumps in the coal can then be broken until none of the coal is larger than "pea" or "bean" size. The mixing and quartering process should be continued until only a few pounds of coal remain. This remainder should be at once put into air-tight canisters, the covers of which must be sealed and also carefully marked for identification.

As the calorific value of coal depends largely upon the amount of ash, and as a higher percentage of ash is contained in dust coal than in large coal, it is essential that when quartering the coal samples as described above, the dust and small coal belonging to the quarters removed should also be taken away. If this is not done, then the percentage of fine coal and dust in

the final sample for the laboratory will be higher than is fair or than it should be.

The thermal balance would be set out as in Table No. XXII. :—

TABLE XXII.

Boiler Test: Thermal Balance.

Heat balance per 1 lb. of dried fuel.	B.Th.U.	Per cent.
Total heat value of 1 lb. of dried fuel	—	—
Heat transferred to the water	—	—
Heat carried away by products of combustion . .	—	—
Heat carried away by excess air	—	—
Heat lost in evaporating and in superheating moisture mixed with the fuel	—	—
Heat lost by incomplete combustion	—	—
Heat lost by unburnt carbon in ash	—	—
Heat lost by radiation, superheating, moisture in air, hot ashes, and unaccounted for	—	—

Banking Losses in Power Houses.—The following Table, No. XXIII., gives the result of a test taken by Mr. E. T. Ruthven Murray at the Willesden Power House, England :—

TABLE XXIII.

Time.	Coal Percentage.				Evaporation.				Lbs. of coal per K.W. hour.		Weight of water per K.W. hour.
	Firing to total.	Banking to total.	Bringing up to pressure to total.	Banking, etc., to firing.	Lbs. water per lb. fuel total.		Lbs. water per lb. fuel firing.				
					Actual.	From and at 212° F.	Actual.	From and at 212° F.	Firing.	Banking.	
	Per cent.	Per cent.	Per cent.	Per cent.							Lbs.
8 a.m. to 4 p.m.	100	—	—	—	8·96	9·61	8·96	9·61	3·24	—	29·03
4 p.m. to 12 a.m.	93·6	—	6·4	6·9	8·81	9·30	9·41	9·91	3·17	0·217	29·77
12 a.m. to 8 a.m.	81·1	9·45	9·45	23·5	11·1	11·47	13·70	14·07	5·70	1·340	78·14
24 hrs.	94·2	1·1	4·7	6·29	9·14	9·65	9·70	10·22	3·34	0·210	32·44

In Table No. XXIV. there are shown the results of a test by Mr. W. A. Vignoles, of Grimsby, England, giving the standby coal during one actual and two estimated weeks with different load factors. The figures show how the variation of load factor affects the amount of coal required for standby purposes :—

TABLE XXIV.

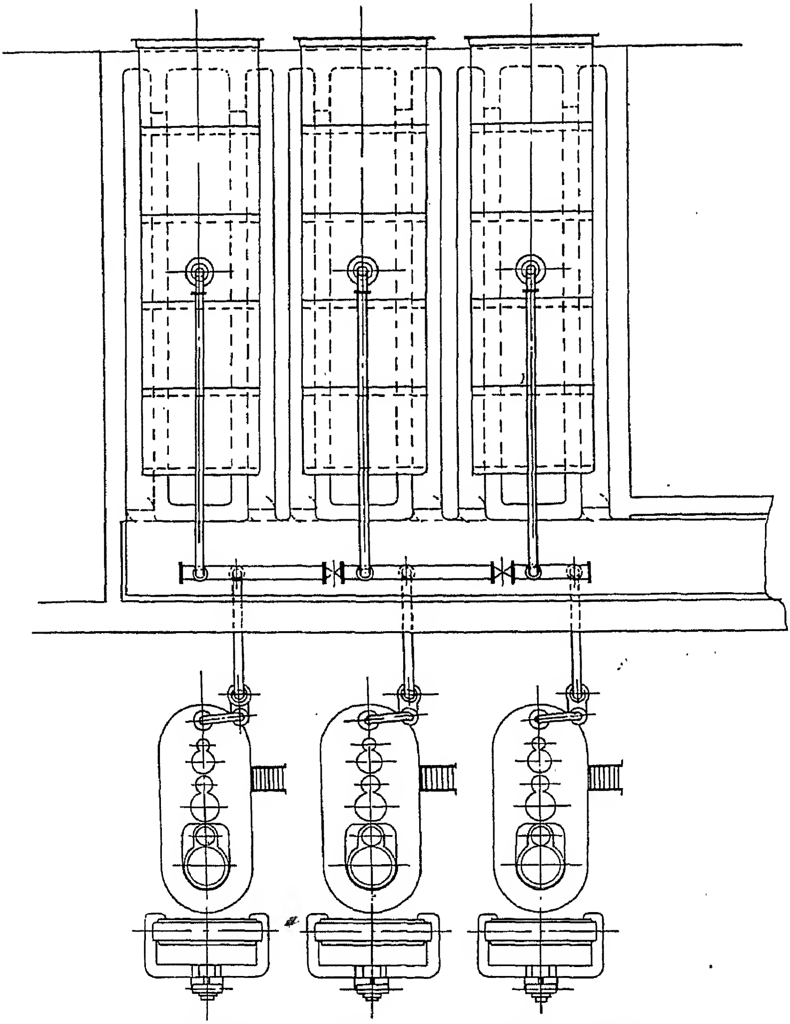
STANDBY LOSSES.

Item.	Actual week.		Estimated week.		Estimated week.	
	Totals.	Per cent.	Totals.	Per cent.	Totals.	Per cent.
[illegible] per week	23,241	—	27,510	—	2520	—
[illegible] r 24 hours	3,320	—	3,930	—	360	—
Maximum load : K.W. .	440	—	640	—	150	—
Load factor . . .	31·5%	—	25·6%	—	10%	—
Number of boilers in use	3	—	4	—	2	—
Total fuel per week : tons	79·75	100	92·0	100	13·75	100
Coal for banking fires in boilers required for peak load : tons . . .	1·5	1·9	3·0	3·3	1·5	10·9
Coal for banking fires on spare boilers and used on peak once a week : tons	2·6	3·2	2·6	2·8	1·0	7·2
Total coal used for standby purposes : tons . .	4·1	5·1	5·6	5·6	2·5	18·1

A large number of records show, broadly speaking, that 20 per cent. of the total coal consumed in power stations is accounted for in getting ready to supply, in banking reserve boilers, and by losses of different kinds, 80 per cent. of the coal being used on actual load. These percentages, while generally correct, vary with the annual load factor, and in stations working on very high load factors the proportion of total coal representing preparation and losses is smaller.

These considerations have an important bearing upon the economy of any power house design, and emphasize the necessity of proportioning the sizes of both boiler and engine units and of arranging the pipework so that the standby losses may be reduced to a minimum.

Lay-out of Boiler House.—Having determined upon the type of boiler, and the unit size of engine or turbine best adapted



Arrangement of One Lancashire Boiler to each 500–600 K.W.

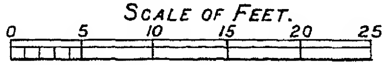


FIG. 11.

for the power house, the designer has to consider the lay-out. There are several typical arrangements, namely :—

(*a*) One boiler to each engine, giving the simplest arrangement of steam pipe, and adaptable to small units.

(*b*) Two boilers in each battery to each engine, adaptable for larger units.

(*c*) Boilers in two parallel rows, where a boiler unit may consist of four individual boilers to each engine; adaptable for still larger units.

(*d*) Boilers on two floors, where one battery may become the boiler unit supplying one turbine; adaptable where space is of great value, and only recommended in exceptional circumstances on account of the cost of the structure.

(*e*) Boilers laid out as shown in Fig. 16, where each group or line of boilers, arranged at right angles to the turbine-room, is the boiler unit. This design is necessary with very large turbines and is now generally adopted.

As simplicity of design is eminently necessary to obtain good results, with as short and direct a pipe range as possible, obviously the best lay-out is obtained by arranging one boiler to each engine, as shown in Fig. 11.

There a drum type (Lancashire) 30′ × 8′ 6″ boiler is shown supplying a 500 K.W. reciprocating engine and generator. The boilers are spaced 11 feet 6 inches apart, which is also a convenient spacing for this type of engine.

In Fig. 12, a 1000 K.W. reciprocating engine is shown. This size requires two Lancashire boilers per engine. It is at once seen that an arrangement of drum boilers in a continuous battery is wasteful of space between the engines, involving an unnecessary amount of room and cost for buildings. The same criticism would apply were the boilers arranged in two rows with the firing floor between them. While the size of the engine-room would be reduced, the area of the boiler house would be increased.

By installing drum boilers of the dryback marine type,

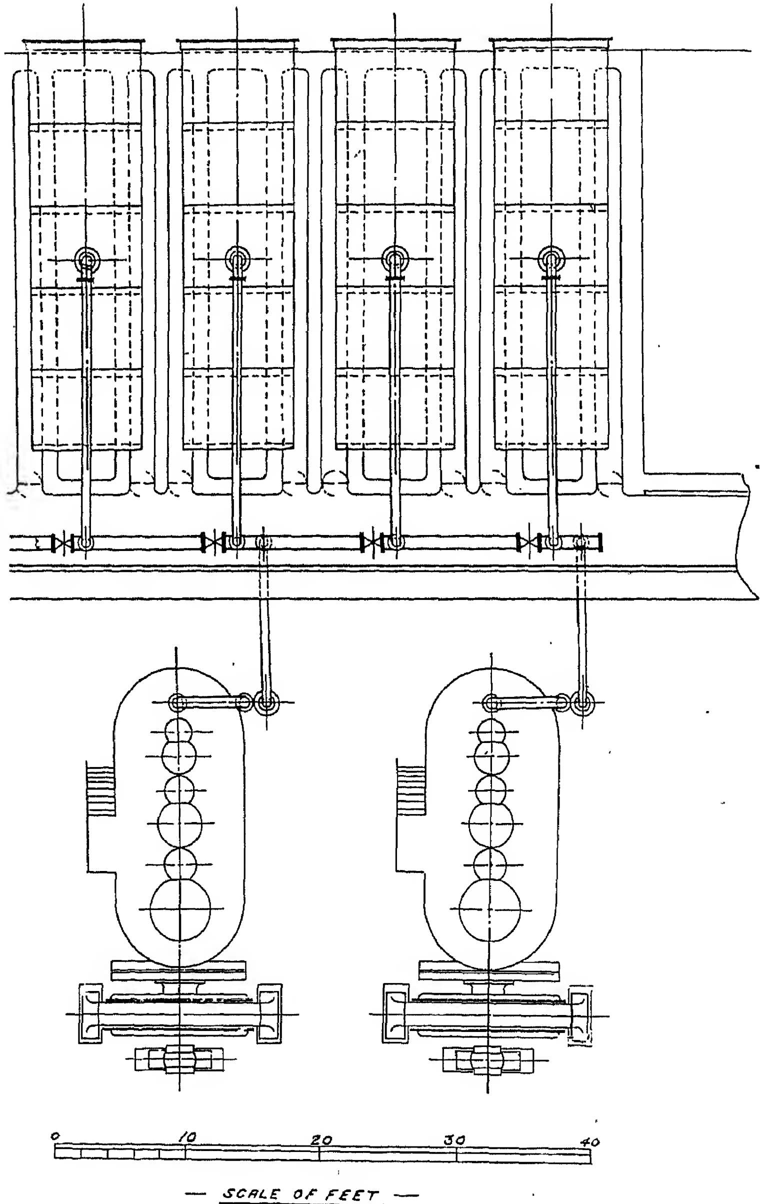


FIG. 12.

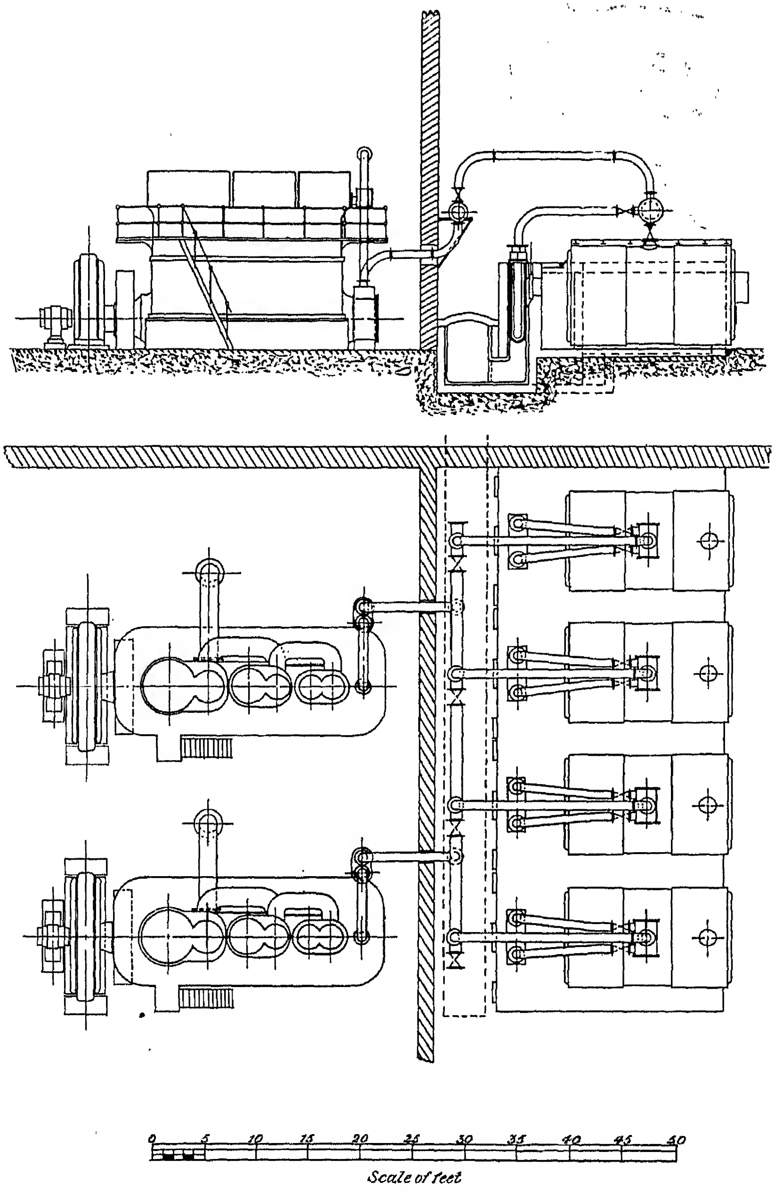


FIG. 13.

however, quite a neat lay-out can be made for power houses of moderate size, as will be seen from Fig. 13.

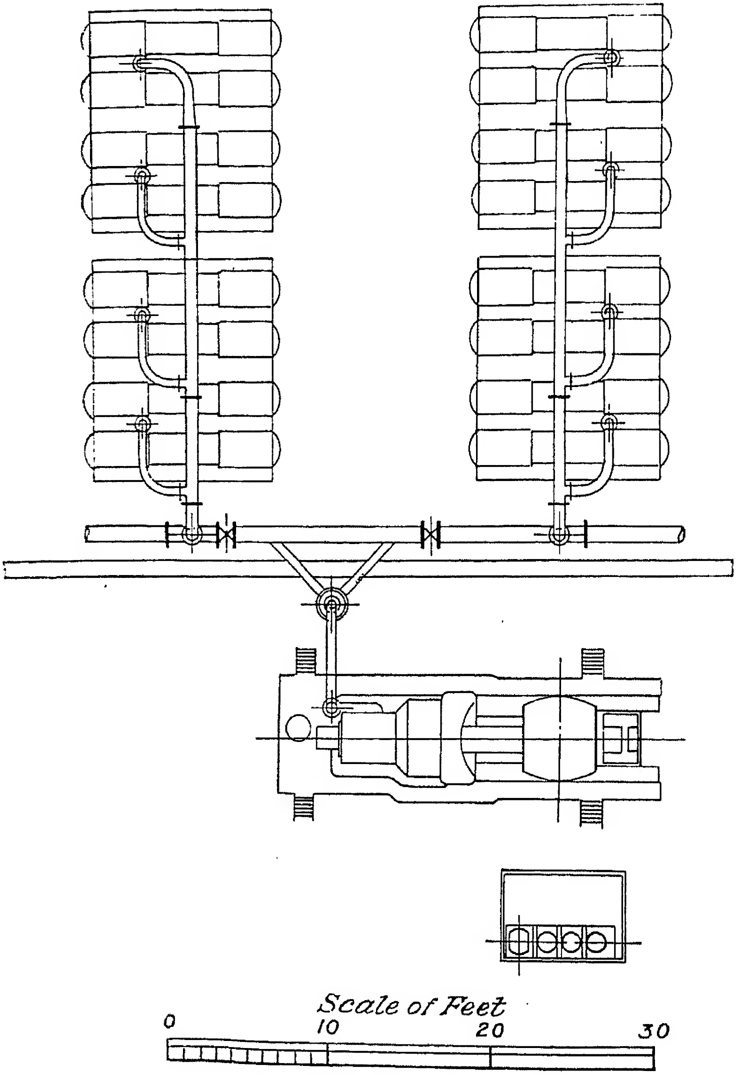


FIG. 14.

The next step is to double-bank the boilers, as shown in the illustration of the Greenwich power house of the London County

Council (Plate III.). The size of the turbine may thus be doubled, and one line of boilers and one engine and condenser may be grouped together to form one complete set. This arrangement is good for medium-sized power houses.

A further development may be made by arranging the lay-out so that four or more boilers and one turbine together form one set. This is illustrated in Fig. 14, where the turbine axis is shown at right angles to the boilers so as to reduce the engine-room span and the cubical contents of the buildings.

A further development still can be obtained by arranging the boilers on two floors. This method is adopted where the site values are very high and greater than the increased expense of the extravagant buildings entailed. A lay-out of this kind has been adopted at the Chelsea power house of the Underground Railways of London, as shown in Fig. 15, at the Interborough Rapid Transit Company's Manhattan Power House in New York (see Plate IV.), and at other places. The Manhattan power house is now supplemented with exhaust turbines.

For still larger stations and those of the largest types a completely different design must be made. In such cases the boiler house is laid off with a double bank of boilers sufficient in number to supply steam to the single large turbine fed from them. This boiler house, complete with its independent stack for each pair of boilers and induced draught fans and pumps, together with the single turbine and its condenser, form one complete unit of plant in the power house. A lay-out of this type, known as the cellular or bulkhead system, is of great importance in a large power house, as in the event of an explosion or other disaster the danger of a complete shut down is minimized. An example of this design is shown in Fig. 16.

The Author would advocate the extension of this principle to the switchgear, so arranging the latter that each separate generator and its auxiliaries is self-contained. The whole switchgear should be fixed in a separate switch house with collecting cables led to two separate control houses from which the transmission lines would radiate and in which the operator would control the whole system by a master keyboard and

relays. This is dealt with later in the special chapter on power house switchgear (Chap. X.).

Lay-outs of the types (*a*), (*b*), or (*c*) above may be used with drum or fire-tube boilers, which are ordinarily arranged in continuous batteries with the usual setting. A space of 3 feet

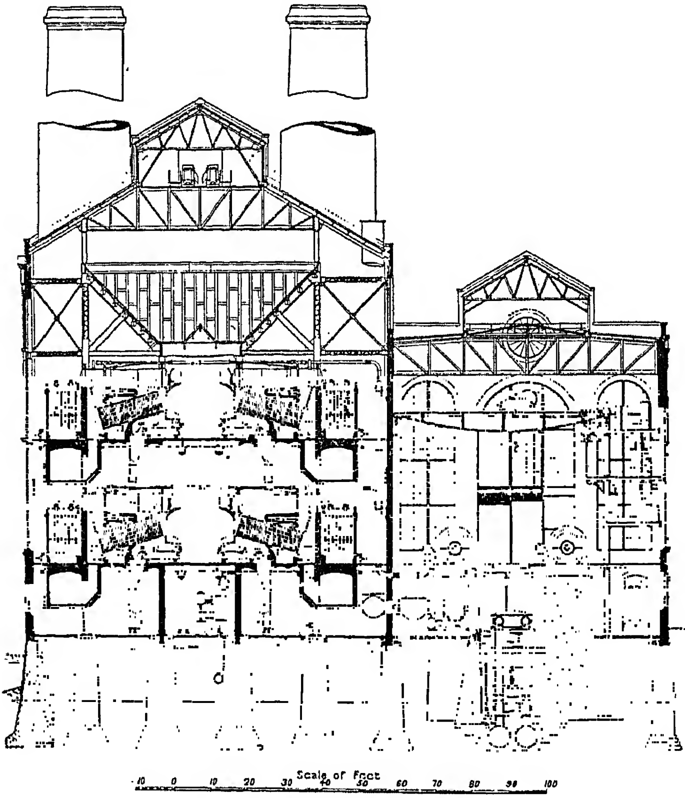


Fig. 15.

is usually required between the shells of each pair of boilers, to allow for the side flues and firebrick division wall.

The five types of arrangement previously indicated are also applicable in the case of water-tube boilers. It is customary, however, to instal water-tube boilers in pairs with inspection ways from 3 to 5 feet wide between each pair, so as to enable access to be given to the various inspection and cleaning doors

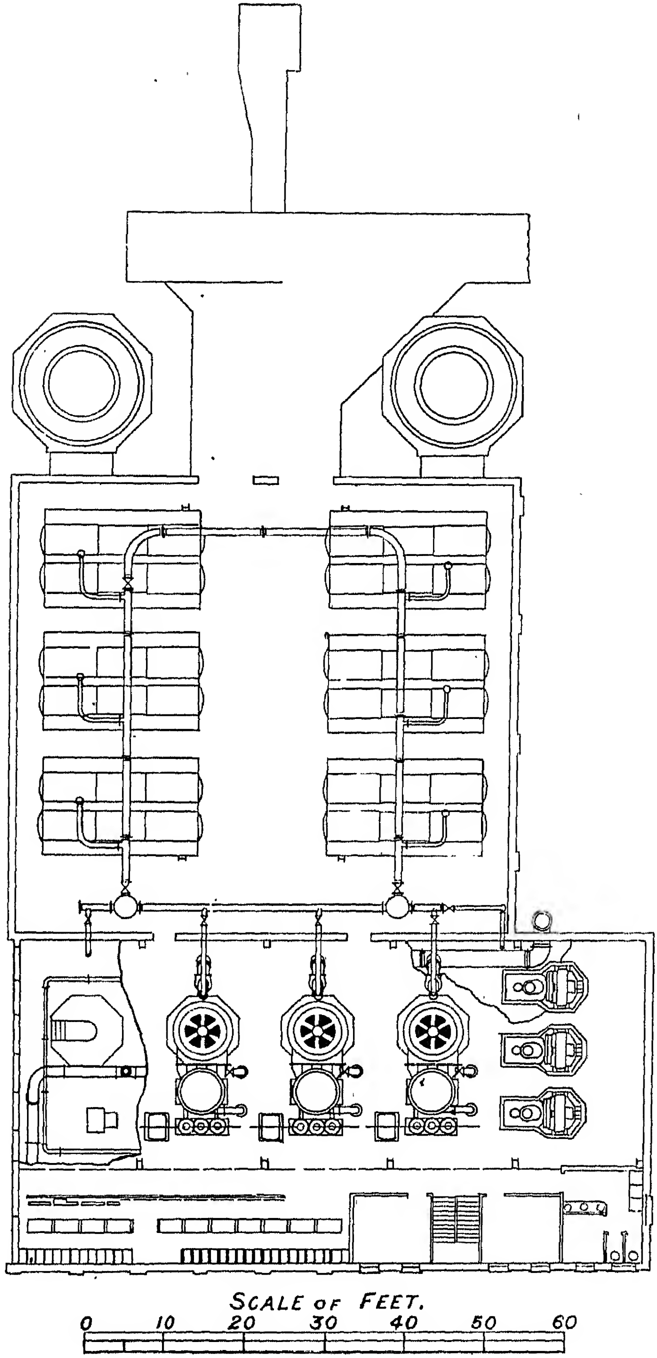


FIG. 16.

and eye-holes. Attention must be given to the amount of space left between the fronts of water-tube boilers and the boiler house walls or opposite faces of the range, so as to enable tubes to be replaced and stokers to be run out for repair and removal. Where space is restricted, windows, or Kinnear folding doors, can often be advantageously arranged opposite to the tubes of each boiler when laid out in single rows, so as to admit of cleaning, etc.

Drum Boiler Settings.—Drum type boiler settings are now quite standardized. The underneath and side flues and the

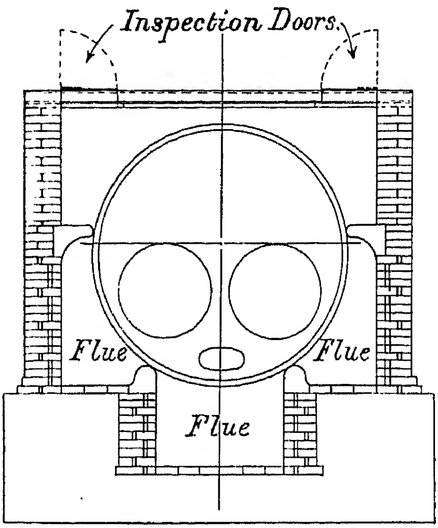


FIG. 17.

combustion chamber are, of course, lined with firebrick, and the drums are placed on specially formed seating blocks of pressed fireclay. These blocks have rounded noses abutting on the drum plate, as shown in Fig. 17, so that while amply strong to resist crushing, only a minimum surface is in contact with the plate, thus allowing a maximum surface for inspection and external contact with the flue gases. Similar blocks which are bonded into the side walls on suitable corbels, are used to close in the tops of the side flues. In boilers of these large dimensions special care must be exercised to prevent air leakage from

the outside, or short circuits of the flue gases from the under flue to the side flues. The boilers are arranged so that the front end plate projects beyond the brick face to enable the exterior angle ring to be clear of the brickwork for inspection. Since these boilers must expand, it is frequently found that the joints between the facing brickwork and the boiler shell become defective and admit air. The Author has found a stemming of asbestos putty useful, being sufficiently elastic to permit of the breathing of the boiler without causing air leakage at that point. The blow-down neck (which must be of wrought steel and not cast) is also provided for in a special recess in the blow-down trench in front of the boilers. Special care must be taken to avoid air leakages through or over the walls forming this recess, since air leakages at this point are sometimes a cause of undue deterioration of the shell plate.

Where superheaters are used with drum boilers it is usual to fix them in the combustion chamber at the end of the boiler setting behind the back plate. Ample space must then be allowed at this point, so as to avoid undue congestion, and special care must be taken in fitting the firebrick quarles over the top of the chamber and around the superheater top box. In order to give the end plate of the boiler drum freedom, and to keep clear of the rivet heads, it is usual to end the chamber cover pieces in an angle iron running parallel with the end plate, as shown in Fig. 18. This makes a neat finish to the chamber top, and prevents the boiler when expanded from compressing and dislodging the cover plates, and effectually prevents air leakage at this point. In setting the dry-back marine type, a good space must be left between the back end plate and end wall of combustion chamber, so as to prevent the flames being reflected and beaten back on the tube ends and burning them.

The ordinary setting, viewed in end elevation, usually finishes about two-thirds of the drum radius above the centre line, the exposed remainder of the drum being covered with non-conducting composition. A chase is left in the top of the side walls to form a key between the boiler lagging and the walls and thus prevent air leakage, as shown in Fig. 19. The

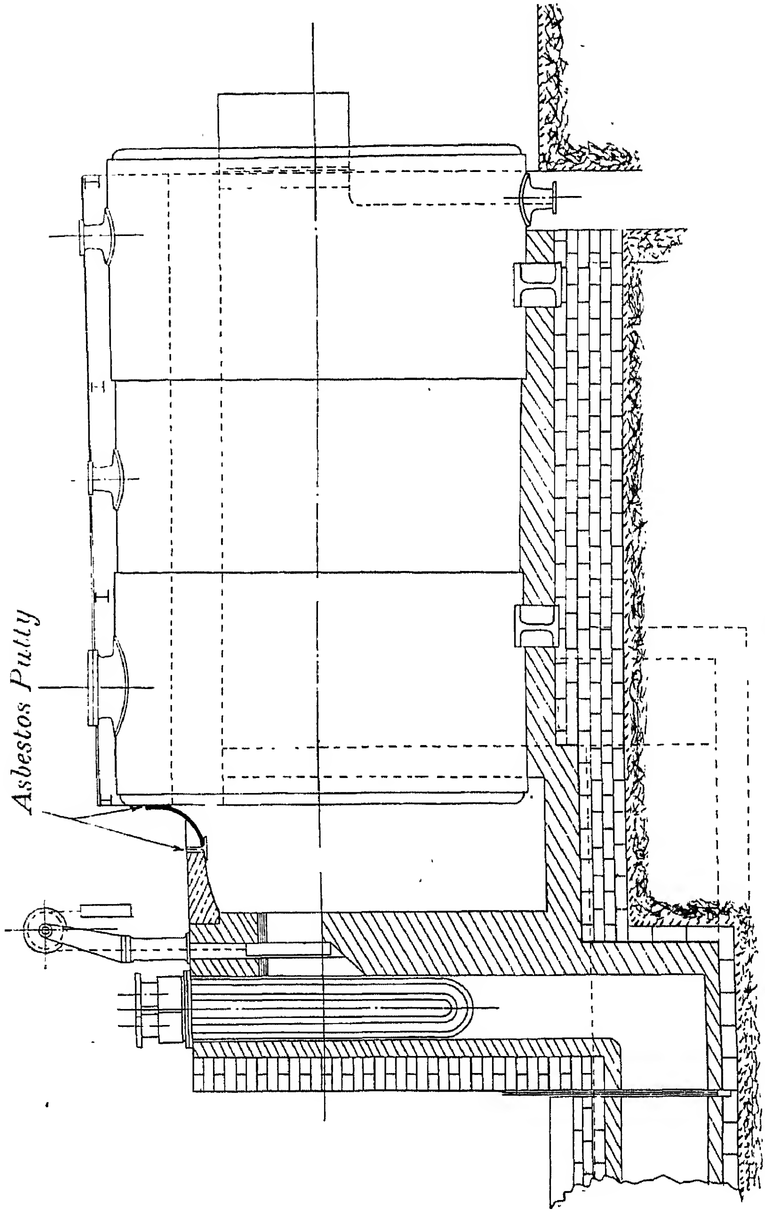


FIG. 18.

Author has successfully used the arrangement shown in Fig. 17, which has the advantage of providing an insulating space between the air and the drum (the latter being covered with removable asbestos mats), and of enabling every seam, butt strap, and rivet head of the boiler to be examined easily without damaging the composition. Moreover, the boiler tops can be conveniently swept down, and a useful operating platform is provided.

Water-tube Boiler Settings.—The settings of water-tube

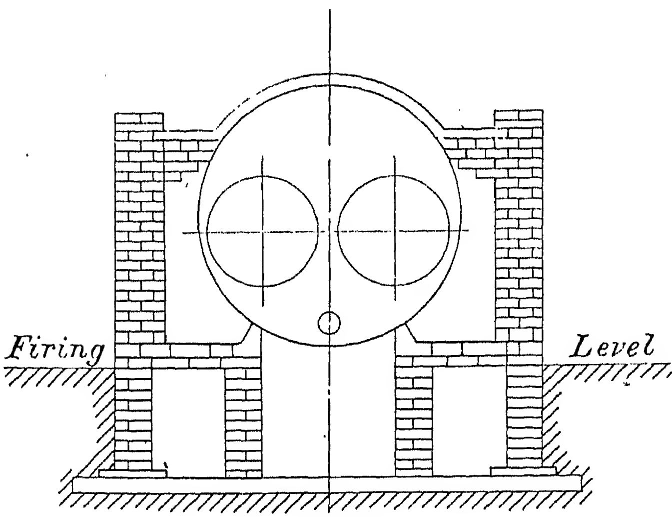


FIG. 19.

boilers are of two principal classes: (*a*) the ordinary brickwork setting, and (*b*) the marine setting.

When using the former, great care must be taken to employ good stock bricks, non-absorbent and of the same dimensions as the firebrick, except that they should be slightly thinner, so as to give a good bond and a thin joint. The bricks, therefore, should be frogged (see specification of materials, p. 81). Outside bricks should be glazed to prevent porosity; failing this, a good coat of bitumastic, tar compound, or similar protection should be laid on, to soak into and seal up the pores and form an air-tight skin. There being such a relatively large surface of

brickwork exposed, good materials and good bricklaying are most essential in the interests of economy. The designer will find that if he carries the side walls up as shown in Fig. 17, and thus provides a durable casing with a flat platform over the boiler drum tops, he will also gain an advantage of easy inspection and absence of air leakage, as was mentioned before.

The marine casings of water-tube boilers are iron plates bolted up to framing with firebrick lining, as previously mentioned, and have the merit of ensuring air-tightness and also of requiring less room. They are particularly useful in some parts of the world where it is difficult to obtain a good stock brick. Firebricks are usually shipped with the boiler, running about 3 tons per 1000 bricks.

A point of leakage frequently overlooked is where the dampers emerge from their guide frames. A practical method of reducing this leakage is to carry an extension spindle up from the damper, to extend the brickwork so as completely to envelope the damper, and to bring out the extension spindle (which must be long enough to emerge when the damper is right down) through a gland built into the brickwork. Dampers should always be man-handled from the boiler fronts, and, of course, counter-weighted.

The sidewalls of water-tube boilers have a lining of firebricks, $4\frac{1}{2}$ inches thick, set in fireclay, this lining being thoroughly bonded to the stock brickwork by headers at every fourth course, beginning at fire-bar level.

The arches over the fire doors, bridge, and hanging bridge over the tubes are built of firebrick set in fireclay, all carefully bonded to the side walls. The hanging bridge wall is built on iron supports built into the side walls, and is carefully fitted around the boiler drum. Baffles, forming divisions across the tubes, are formed of special firebricks grouted with fireclay and bonded to the side walls.

Specification of Materials for Boiler Settings.—Concrete is usually specified to be composed of one measure of Portland cement to six of aggregate, the latter being in the proportion of four of broken stones (to pass through a 2-inch ring) and two of sharp, clean sand. The materials to be accurately measured

and mixed together in a dry state on a hard, clean platform; water then to be added and the whole to be thoroughly mixed.

Mortar to be made in the proportion of one measure of lime of the best quality (measured before slaking) to 2½ measures of sand, thoroughly mixed together.

Portland cement mortar to be mixed in the proportion of three measures of sand to one of cement. The cement to be of the best quality, perfectly cool, and not to weigh less than 112 lbs. per striked Imperial bushel of 2218 cubic inches, when lightly filled and without shaking down; the specific gravity of the cement when fresh burnt and ground to be not less than 3·15. The cement to be ground fine so as to pass through a sieve of 76 × 76 or 5776 meshes to the square inch, without leaving a residue of more than 3 per cent., and a residue of not more than 18 per cent. when sifted through a sieve of 180 × 180 or 32,400 meshes per square inch. A briquette, after immersion in water for seven days, to show in a testing machine a tensile strength of not less than 400 lbs. per square inch, and not less than 500 lbs. after twenty-eight days from gauging.

Sand to be clean and sharp fresh water grit, washed free from loam and other impurities.

Firebricks to be machine made, sound, kiln burnt, of uniform size, and free from cracks or flaws.

To ensure the best results, fireclay should be obtained from the same works as the firebricks; from one-half to three-quarters of a ton being required for setting 1000 bricks. The fireclay grout in which firebricks are set to be mixed very thin and the firebricks to be dipped in it (that is, the fireclay should not be laid on with a trowel) before being laid.

Glazed and facing bricks to be machine made, sound, square, and tough, kiln burnt, of uniform size, to ring clearly on being struck together, and entirely free from line or other defects. Not to absorb more than 7 per cent. of their weight of water after being thoroughly dried in an oven and then immersed in water for twenty-four hours. These bricks to be thinner than the firebricks. No bats or broken bricks to be used, except for closers. All brickwork to be laid in line, with level courses. Joints in stock brickwork not to be more than ¼ inch thick.

Flues.—The areas of flues for hand fired boilers are usually from $\frac{1}{5}$ to $\frac{1}{7}$ the total grate area of the boilers delivering into them. When forced draught is adopted, or other types of mechanical stokers having a high rate of combustion per square foot of grate area are employed, then the area of the flue must be increased, and obviously should be proportioned to the quantity of fuel consumed.

It is good practice to allow 0·55 square foot of flue area for each 100 lbs. of coal burnt per hour. This gives the flue gases a velocity of 30 feet per second, assuming the temperature of the escaping gases to be 550° Fahr., and the gases to contain from 10 to 12 per cent. of CO_2. If the gases are cooled down to 400° Fahr., then the flue area for each 100 lbs. of coal burnt per hour may be reduced to 0·44 square foot.

Flues must always be arranged as short and direct as possible, and preferably with an upward gradient toward the shaft. All flues must be constructed so as to offer the least resistance to the flow of the gases, and must therefore be smooth inside, arranged with easy bends of good radius, with no sharp turns, and so built as to avoid eddies or cross-currents from boilers delivering into them. Flues are usually built up at 14-inch stockwork set in mortar, with a $4\frac{1}{2}$-inch firebrick lining set in fireclay and bonded by headers at every fourth course into the main walls of the flue. The arrangement of dampers must be such as to permit of sections being shut down periodically without laying off an unjustifiable proportion of the total boilers installed; and for cooling down for the removal of soot and ashes. This is specially necessary in the tropics. Access doors must be suitably arranged for the latter purpose; and in designing the boiler lay-out, access from outside the flue must be given so as to permit the removal of the soot by barrows, without unduly upsetting the cleanliness of the boiler-room. Special care must be given to access doors and frames, damper frames, and spindles to ensure air-tightness. Dampers should preferably be of the swivel type, with extended spindles; but where drop dampers are necessary, extended spindles must also be used so as to recover the damper in the event of its operating chain breaking. In lining out the flues with firebrick thin joints

must be used, and care must be taken to select a stock brick (with frog) of slightly thinner dimensions than the firebrick so as to ensure a good bond. It is good practice to fix headers at every fourth course of the 4½-inch firebrick lining, bonding into the stockwork, so as to prevent any bulging and collapsing of the firebrick lining.

It is now more usual to avoid long flues, which are wasteful on account of air leakages and heat absorption, and also to avoid grouping boilers on a flue, which is a "weak link in a chain," as it were. Boilers, especially those with evaporations of 25,000 lbs. per hour and over, should be paired with one short steel chimney shaft between them, and provided with two induced draught fans either of which is capable of drawing off the products of combustion from both boilers. The fans are generally arranged on the economiser deck so that the gases pass continuously upward from the boilers, through the economiser and to the fans and shaft.

Mechanical Stokers.—With the large grates now adopted in power houses, it is almost imperative to use some form of mechanical stoker. For bituminous coals nothing can really beat the chain-grate type, which ensures an even distribution and is easily controlled and repaired. Moreover, owing to the revolving motion, the links have a long life. These stokers are, of course, only adaptable to water-tube boilers, and they are now usually given an inclination towards the fire bridge so as to provide a deeper combustion chamber at that end. The only objection to them is that at very light loads the fire is thin, and there is a tendency to form air cavities with an excess of CO.

The stoker, as shown in Fig. 20, is provided at the rear end with air shutters, operated by a single lever or by two levers, to adapt it for working on variable loads. Thus on light loads the air supply to the rear of the stoker can be regulated and restricted so that practically the same percentage of CO_2 in the furnace gases can be maintained as at times of heavier loads.

The chain-grate stoker is driven from a light countershafting by a very small motor or steam engine, from which movement is imparted to the stoker rocker by a motion rod working from

an eccentric, or, better still, by means of a Morse silent chain-drive. For each stoker, up to a width of 7 feet, 1 B.H.P. is allowed; and for stokers of greater width, from 1½ to 2 B.H.P. per stoker. These figures are inclusive of the power absorbed by the countershafting.

In the underfeed stoker, shown in Figs. 21 and 22, the fuel is deposited in the hopper A, and taken under the fire by a reciprocating sliding bottom running the full length of the trough. The coal rises from the trough, and is distributed thence to the sides of the grate by moving bars. The coking and also the

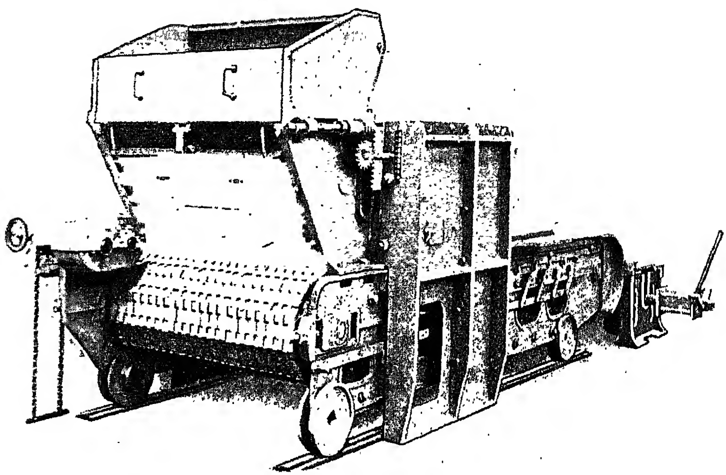


Fig. 20.

burning coal is constantly carried by the moving bars to dumping trays along each side wall, where the clinker and ash are deposited. These trays are hand operated from the boiler face, enabling the ash and clinker to be discharged. The sliding bottom in the trough (shown in Figs. 21 and 22), is driven by a steam cylinder, and the number of strokes can be varied from one in three minutes to fifteen in one minute, each stroke carrying about 6 lbs. of coal. There is thus a very considerable range in the amount of feed. Air enters the grate from the forced-draught air trunk shown in Fig. 21, and is controlled by a wind gate shown at O. The air enters a wind box Q, passes upward

along each side of the trough, and is discharged through an aperture R (Fig. 22), and also through the hollow bars into the

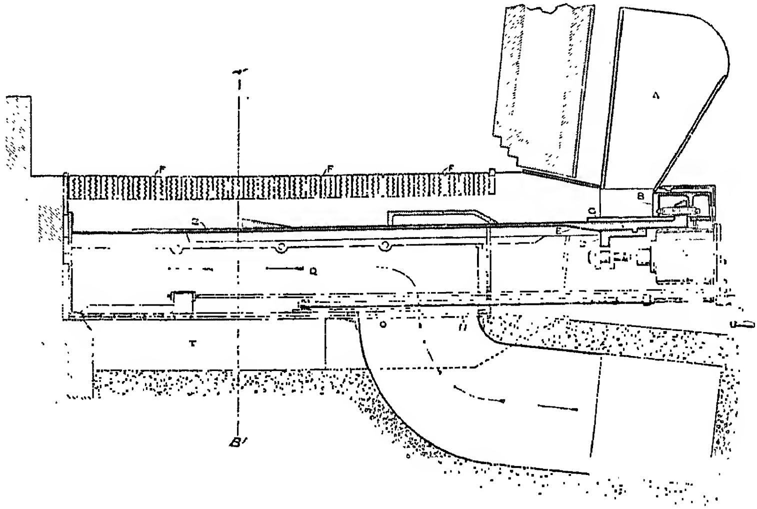


Fig. 21.

ashpit, whence it rises through the space between the bars, to the grate. The bars are thus kept cool and the air temperature in the ashpit is raised to about 350° or 400° Fahr.

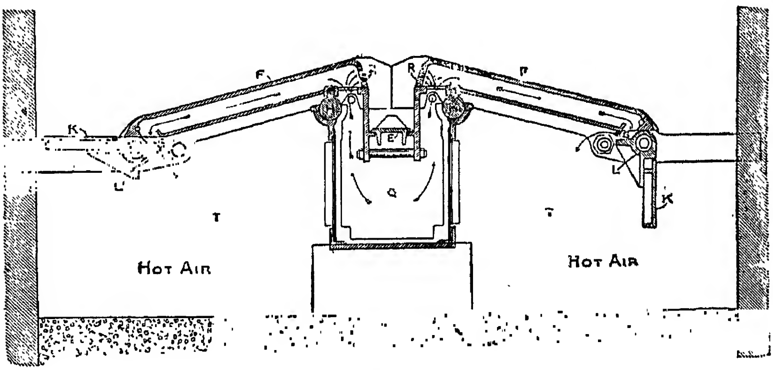


Fig. 22.

The under-feed type of stoker is an excellent machine where anthracitic coal has to be used, and can be adapted for either internal combustion or water-tube boilers with very good results.

For the latter type it is necessary to provide forced draught blowers with distributing air trunks to the various furnaces.

Draught Gauges.—It is well to fix a small draught gauge to each grate for the instruction of the stoker or boiler-house foreman, as well as a main draught gauge at the base of the uptake or chimney. These should preferably be of the water column type.

CO_2 Recorders.—There are several types of carbon-dioxide recorders, one of which should always be fixed to each range of boilers with a tube from each boiler flue to the recorder, the exit pipe to provide the necessary pressure gradient being led into the chimney. These tubes should be of glass so as to permit of easy examination, since they are so likely to be choked with dust, soot, and fine ashes.

The Sarco recorder may be taken as illustrative. A ¾-inch pipe from the combustion chamber of each boiler, with control cocks on each branch, is led to the instrument, and another pipe of the same size is led from the instrument to the chimney. The power required to draw and deal with the gas samples is obtained from a fine stream of water with a head of about 2 feet (3 to 5 gallons per hour being required). By this means the gases are drawn through certain parts of the instrument and made to bubble through a solution of caustic potash (sp. gr. 1·27), by which process the carbon dioxide is absorbed rapidly and completely. According to the amount absorbed so is the height of travel of a float varied, and by means of a pen an automatic record is taken on a chart. The height of the lines marked by each displacement of the float registers the percentage of CO_2.

Such recorders should be checked periodically by more elaborate laboratory apparatus.

Although, theoretically, a high percentage of CO_2 in the flue gases points to a high efficiency of combustion, discretion must be used in placing too great reliance on this one factor. In practice certain coals cannot be burnt efficiently without a fairly high excess of oxygen in the combustion chamber, with a corresponding diminution of CO_2 in the gases; in the case of such coals better results are obtained with a comparatively low percentage of CO_2 in the furnace gases.

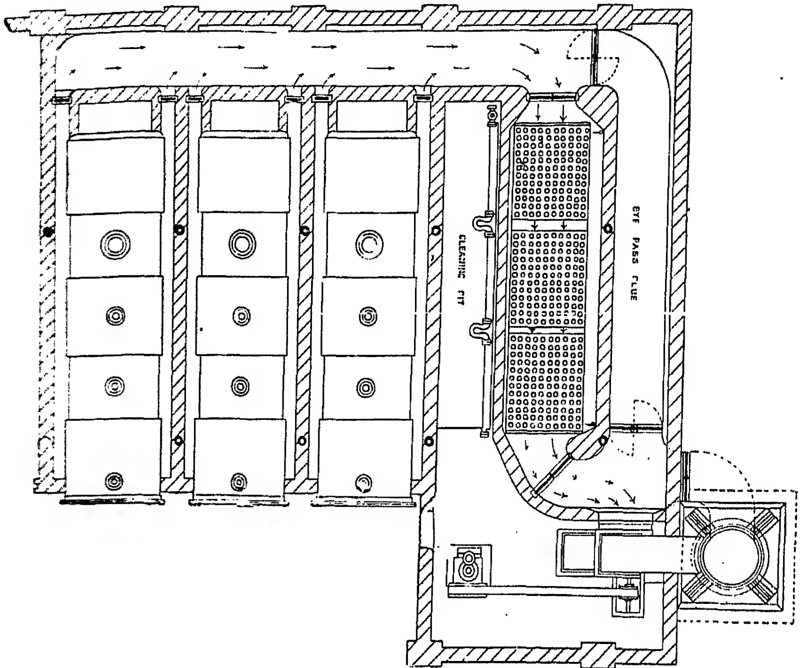
For any particular class of coal, the power-house engineer should determine, by a series of careful tests, the best practical percentage of CO_2 which must be obtained, and then give instructions for that figure to be worked to.

Mechanical Draught.—In designing the lay-out of boiler plant for power houses it is well to remember that (*a*) some of the plant is always at work throughout the year; (*b*) flues must be cleaned and chimneys or shafts repaired without stopping or imperilling the supply; and (*c*) the variations of load are better met by an easily regulated artificial draught. With regard to the latter, peak loads and emergencies can be better dealt with (and the commercial value of any battery of boilers thus raised), by working on the overload capacity of the boilers, though doubtless at the sacrifice of some efficiency during such periods.

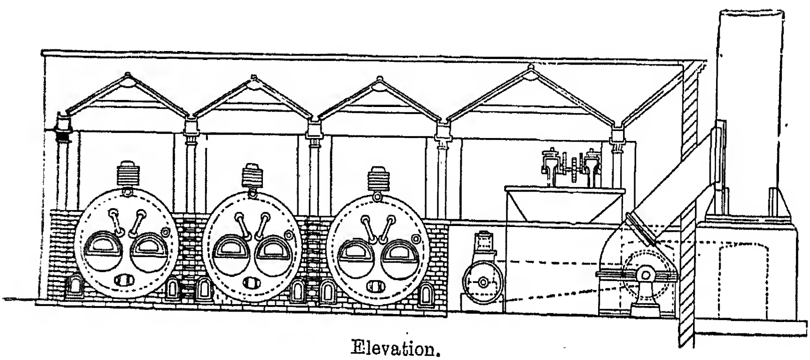
Therefore in a completed design there should always be an alternative shaft, unless the whole power house is built on the bulkhead principle. For small installations two small steel shafts with forced or induced draught plant are to be preferred to one larger or more costly brick shaft with natural draught. Again, in most cases, owing to the variability of the electrical output, the range of evaporation of the boilers is often a wide one. Means of varying the draught are therefore desirable. The energy required to drive the auxiliary draught plant is more than compensated for by the useful absorption of heat units from the flue gases by economisers, the final temperature of the gases at the exit from the economiser being reduced to a much lower figure than would of course be possible under conditions of natural draught with a chimney not unduly high. Generally speaking, induced draught fans are adopted for bituminous fuels with chain-grate or other open-grate types of stoker, and forced draught fans for anthracitic coals with closed grates. Fig. 23 shows a typical arrangement of induced draught fans with motor-drive and bye-pass flue, and Fig. 24 a typical arrangement of forced draught fans with air trunk and ducts for closed grates.

It is best to arrange both forced draught fans for providing a plenum of air under the grates and induced draught fans for withdrawing the products of combustion, thus forming a balanced draught system and reducing the air leakage at the

grates, with greatly increased efficiency. A typical lay-out of a self-contained boiler unit, with forced and induced draught fans



Plan.



Elevation.

Fig. 23.

for the balanced draught system, economiser, and independent steel chimney for each pair of boilers is shown in Plate V. which

illustrates the design of Messrs. Preece, Cardew & Rider for the new Harbour power station for the City of Belfast.

Each Stirling boiler has a grate area of 264 square feet, a heating surface of 8166 square feet, and a normal evaporation

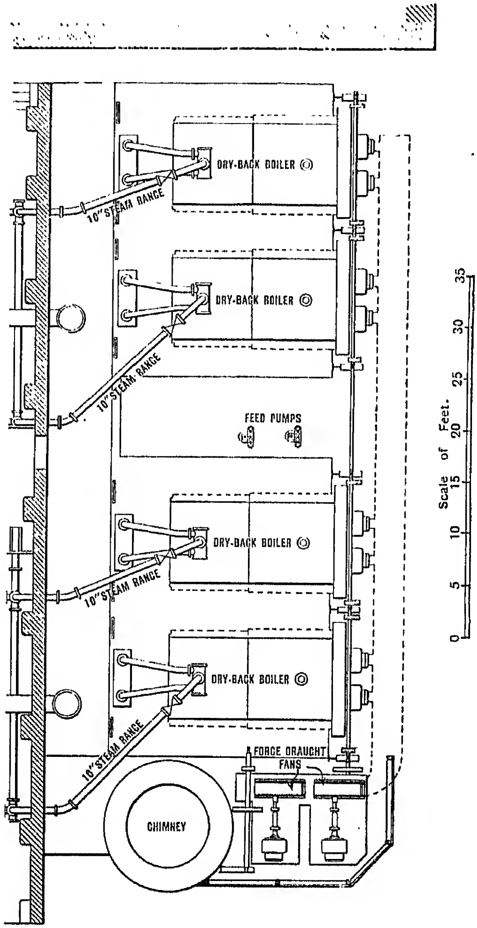


FIG. 24.

from and at 212° Fahr. of 55,000 lbs. of water per hour. The superheater is designed to raise the total temperature of the steam to 650° Fahr. Each forced draught fan is designed to deliver 32,000 cubic feet of air per minute against a pressure of 1½ inches of water, and is driven by a D.C. motor developing

16 B.H.P. at a speed of 420 R.P.M. Each induced draught fan is designed to deliver 60,000 cubic feet of gases at a pressure of $1\frac{3}{4}$ inches of water, and is driven by a D.C. motor developing 38 B.H.P. at a speed of 425 R.P.M. Each economiser has a heating surface of 5700 square feet and raises the feed water from an inlet temperature of 150° Fahr. to a temperature of 325° Fahr. The steel chimney is $9\frac{1}{2}$ feet in diameter, and the cap is 100 feet above grate level. Particulars of the steel structure carrying the economiser, induced draught fan and chimney can be obtained from the illustration.

Power required for Fans.—The power required to drive a fan supplying any particular battery of boilers can be calculated as follows :—

If D = density of flue gas in lbs. per cubic foot,
A = area of discharge opening in square inches,
V = velocity of gases in feet per second, i.e. the peripheral speed of the fan blades ;

$$\text{then K.W. input to motor} = \frac{DAV^3}{2,454,000}$$

assuming 55 per cent. efficiency of fan and 92 per cent. average efficiency of motor.

Another method of calculation is given by the following formula :—

$$\text{Brake H.P.} = \frac{W \times C \times A \times P \times 5{\cdot}2}{60 \times 33,000} \times \frac{100}{E}$$

where W = average weight of coal consumed per hour in lbs.
C = number of cubic feet of air required per lb. of coal ; say 300 cubic feet under ordinary working conditions.
A = ratio of volume of gas at flue temperature (T) to volume of air at, say, 50° Fahr. (T_1).

$$\text{i.e. } \frac{461 + T}{461 + T_1}.$$

P = pressure or draught in inches of water at the fan.
E = percentage efficiency of the fan.
5·2 = the factor for converting the pressure or draught from inches of water into lbs. per square foot.

The average efficiency of fans varies from 52 to 55 per cent., and if one substitutes the former figure and takes 300 cubic feet of air as being required per lb. of coal, the formula resolves itself into

$$\text{B.H.P.} = \frac{W \times A \times P}{660}.$$

This figure represents the brake H.P. required to drive the fan, and does not take into account the efficiency of the motor.

Batteries of boilers aggregating 100,000 lbs. evaporation per hour or more may be taken as requiring a fan-draught motor of 0·55 B.H.P. per 1000 lbs. evaporated per hour.

It is essential to duplicate the fans and motors so as to have a complete reserve in the event of any failure of the one set.

Fans may be supplied with $\frac{1}{2}$, $\frac{3}{4}$, or complete steel housing according to the position in which they are to be placed, but it is a point of good design to arrange them so as to keep the bearings away from the flue gases. Owing to the heat conducted from the fan blades and spider, the bearings usually have to be water-jacketed. The driving motors can either be of the squirrel cage 3-phase slip-ring type, or direct current. Since the delivery of air must vary somewhat as the load on the power house (though not directly, the power required by the fan being proportionate really to the cube of the speed), provision for speed variation is essential. This is especially easy in the case of direct current motors with double-wound armatures, although the squirrel-cage motor can also be given, say, three regular speeds by means of a controller and resistances. The motors are usually direct coupled to the fan shaft with water-jacketed bearings as shown in Fig. 25, but the fans are sometimes rope driven. The former should be adopted whenever practicable, owing to the consequent reduction of space required.

The capacities of some standard sizes of Sirocco induced draught fans made by Messrs. Davidson & Co. of Belfast (which may be taken as typical of high-class fan practice) are indicated in Table No. XXV. together with the speeds and approximate B.H.P. required. The first columns relate to fans for flue temperatures of 500° Fahr. and apply to cases where economisers are not used, and where the flues are of normal area and without

objectionable bends. The other columns relate to fans for flue temperatures of 400° Fahr. and apply where economisers with moderate heating surface are used, a higher water gauge thus being required to overcome the extra flue resistance. In both cases the B.H.P. specified is an outside figure. If variable speed

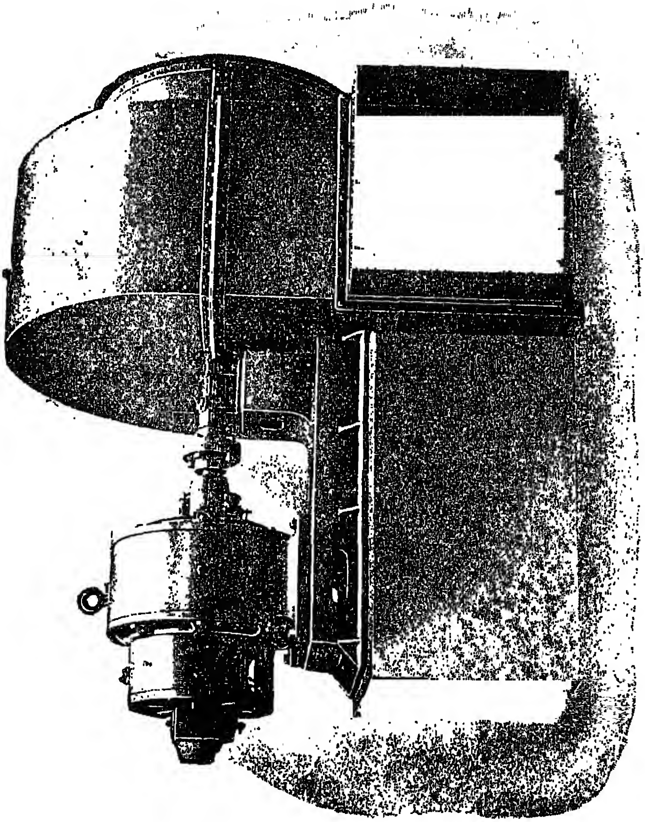


Fig. 25.

motors are adopted, it will be found that under usual and normal conditions of operation, the H.P. will work out a good deal below that given in the table. It is the rule, however, to provide motors of liberal rating, particularly in the case of variable speeds, so that the draught power can be increased when

necessary to meet a sudden increase of load on the boilers, or a change in the class of fuel.

TABLE XXV.

STANDARD SIZES OF SIROCCO FANS.

Temperature of flue gases 500° Fahr. : water gauge 1½ ins.			Temperature of flue gases 400° Fahr. : water gauge 2 ins.		
Amount of coal in lbs. per hour.	B.H.P. of fan.	Speed. R.P.M.	Amount of coal in lbs. per hour.	B.H.P. of fan.	Speed. R.P.M.
800	4	1000	—	—	—
2,000	9	620	2,300	14	660
3,800	17	480	4,300	24	530
6,100	27	400	7,000	36	420
7,500	34	360	8,500	40	450
9,000	40	330	10,000	49	400
10,000	43	300	11,000	56	355
11,500	47	277	12,000	60	368
13,000	53	260	14,000	68	335
—	—	—	24,000	115	255

NOTE.—The pre-war price of induced draft fans for direct coupling to, but exclusive of motors or engines, was approximately £100 per 5000 lbs. of coal per hour.

Chimney Shafts for use with Forced or Induced Draught.— The dimensions of shafts in connection with artificial draught may be based on a gas velocity in the vertical shaft of 30 feet

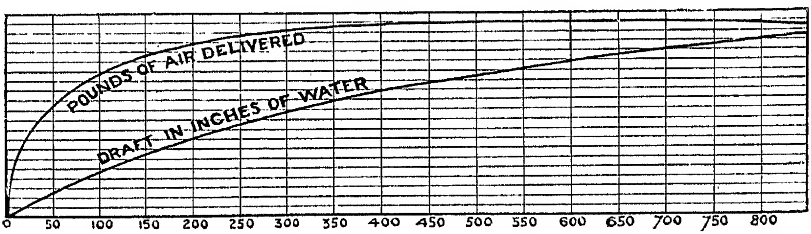


FIG. 26.

per second. From each pound of coal burnt there is a yield of from 13 to 30 lbs. of gas, the volume of which of course varies with its temperature.

Fig. 26 gives curves showing the draught in inches of water

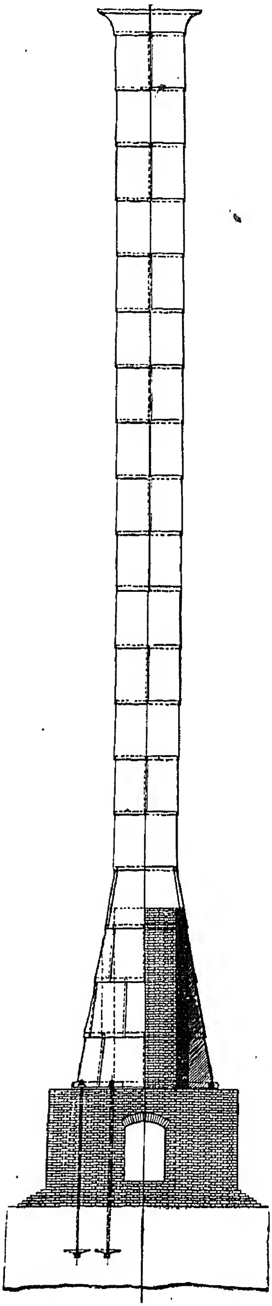


FIG. 27.

for a chimney 100 feet high, and also the relative quantities of air (in lbs.) which would be delivered in equal times, in each case under temperature differences ranging from 50° to 800° in excess of the temperature of the external atmosphere which is taken at 60° Fahr. The vertical scale for the draught curve is full size each division representing $\frac{1}{20}$ inch. With regard to the curve for quantities of air, it will be seen that nothing is gained by carrying the temperature difference beyond 400°.

With forced or induced draught plants, the shaft has no other function than to discharge the gases at a sufficient height so as not to create a nuisance.

Steel Chimney Shafts.—As previously mentioned, it is now more usual to equip power houses with short steel stacks and forced or induced draught. Such stacks, in addition to obviating the use of long flues, have advantages as regards portability, small weight, and ease of erection and subsequent inspection. For example, the weight of a steel shaft having an internal diameter of 9 feet and a height of 100 feet only amounts to 18 tons, exclusive of brickwork. On the other hand, steel shafts require frequent scraping and painting, especially in manufacturing districts where traces of corrosive agents occur in the atmosphere. A typical steel shaft is illustrated in Figs. 27, 28, and 29; the first figure gives an elevation, the second a plan, and the third a section through the base plate to show a foundation bolt.

Typical Specification for Steel Shaft. — The following general specification for 100-foot shaft may be taken as typical. Such a shaft will deal with a maximum load of 5000 K.W. on a basis of 4 lbs. of hard steam coal per K.W. hour.

(*a*) The shaft to have an internal diameter of 9 feet measured inside the firebrick lining, and a clear height of 100 feet above grate level. The shaft to be coned from the base to a height of about 40 feet, and the diameter at the base to be about 15 feet. To be constructed in sections as follows :—

Bottom section : 45 feet, of $\frac{5}{16}$-inch plates.
Top section : 40 feet, of $\frac{1}{4}$-inch plates.

The plates to be well riveted together and lined with firebrick to a height of 35 feet from the base. The whole structure

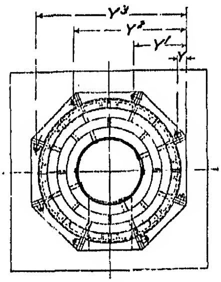


FIG. 28.

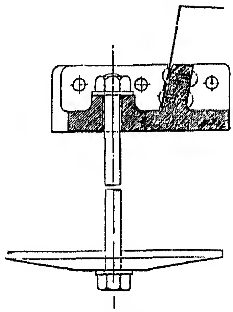


FIG. 29.

to have a factor of safety of 5, based on a maximum wind pressure of 50 lbs. per square foot.

(*b*) The base to be built up of segments of good grey-coloured close-grained pig-iron, secured by foundation bolts to a brickwork plinth lined with firebricks into which the flues are to be led.

(*c*) The shaft plates to be shaped to proper curvature by rolling cold, and the whole to be laid out accurately at the makers' works and all rivet holes drilled. The plates to be made from the best mild acid open-hearth steel, with a tensile strength of 28 to 32 tons per square inch, and an elongation of not less than 20 per cent. in a test length of 8 inches.

(*d*) The cap to be made from cast-iron, belled and reinforced by steel angle stiffeners.

(*e*) The rivets to be made from open-hearth acid steel, with a tensile strength of 24 to 28 tons, and an elongation of not less than 28 per cent. in a length of 2 inches. The usual bending and flattening tests are also to be specified.

(*f*) The shaft is usually provided with a safety ladder, riveted to the exterior, and facilities should be afforded for painting by fixtures attached to the cap from which the usual painters' cradle may be swung.

(*g*) Lightning conductors and roses are provided in the usual way.

Dimensions of Steel Chimney Shafts.—There must be a certain relation between the exposed area and the height, weight, and breadth of base to enable the shaft to withstand successfully the overturning moment due to severe wind pressure. This relation is expressed by the formula

$$W = C\frac{dH^2}{B}$$

where W = weight of shaft in lbs.,
C = coefficient of wind pressure per square foot of area, usually taken at a value of 28 for circular shafts,
d = average external diameter of shaft in feet,
H = height in feet,
B = breadth of base in feet.

The size of foundation bolts is obtained from the formula

$$S = \frac{C \times d \times H^2}{2} - \frac{W \times B}{2}$$

where S = total stress on all the bolts in lbs.-feet (this should never exceed 8000 lbs. per square inch),
C = coefficient as in the previous formula,
d = average diameter in feet,
H = height in feet,
W = total weight of shaft in lbs. above the *cast-iron base*,
B = diameter of base plate in feet.

The stress on each foundation bolt can then be determined from S in the following manner:—

$$S_1 = \frac{S \times y_3}{2(y_3^2 + y_2^2 + y_1^2 + y^2)}$$

where y_3, y_2, y_1, etc., are the dimensions (in feet) measured from one edge of the base plate to the successive centres of the foundation bolts (see Fig. 28).

Natural Draught Chimneys.—The approximate sizes of natural draught shafts for boiler plants of given total evaporative capacities per hour under average practical conditions are as given in Table No. XXVI.

TABLE XXVI.

SIZES OF NATURAL DRAUGHT SHAFTS AND BOILER PLANTS.

Shaft diameter in inches.	Height of shaft in feet above grate level and evaporative capacities of boiler plants (in pounds per hour).						Side of equivalent square shaft.	Effective area.	Actual area.
	100 ft.	110 ft.	125 ft.	150 ft.	175 ft.	200 ft.	ins.	sq. ft.	sq. ft.
48	10,500	11,000	11,700				43	10·44	12·57
54	13,500	14,200	15,100	16,600			48	13·51	15·90
60	17,000	17,800	19,000	20,800	22,500		54	16·98	19·64
66	20,900	21,900	23,300	25,500	27,600	29,500	59	20·83	23·76
72	25,100	26,300	28,100	30,700	33,200	35,500	64	25·08	28·27
78	29,900	31,200	33,300	36,400	39,300	42,000	70	29·73	33·18
84	34,900	36,500	38,900	42,600	46,000	49,200	75	34·76	38·48
90	40,400	42,500	44,900	49,200	53,100	56,800	80	40·19	44·18
96	46,200	48,500	51,600	56,300	60,900	65,800	86	46·01	50·27
102	—	—	58,400	64,000	69,100	73,900	90	52·23	56·75
108	—	—	65,800	72,100	77,900	83,200	96	58·83	63·32
114	—	—	73,800	80,700	87,100	90,100	101	65·83	70·88
120	—	—	—	89,700	96,900	103,600	106	73·22	78·54
126	—	—	—	99,300	107,200	114,600	112	81·00	86·59
132	—	—	—	109,300	118,100	126,200	117	89·19	95·03
138	—	—	—	119,800	129,700	138,300	122	97·75	103·86
144	—	—	—	130,800	141,000	151,000	127	106·72	113·10

The last figures in the table represent the advisable limiting size of plant delivering into any one shaft; as before mentioned, two or more shafts should be provided for large plants.

Draught in Chimney Shafts.—The draught of a chimney having an area suitably proportioned to deal with the volume of gases depends, of course, on its effective height, and is proportional to the difference between the weight of the column of air outside and that of the column of lighter gases inside.

The effective draft in inches of water may be found from the following formula:—

$$D = H\left(\frac{7{\cdot}6}{T} - \frac{7{\cdot}9}{T_1}\right)$$

where D = draught in inches of water at base of shaft,
H = height of shaft in feet above grate level,
T = absolute temperature in degrees Fahr. of external air, i.e. $t + 461$,
T_1 = absolute temperature of internal air, i.e. $t_1 + 461$.

Coal Storage and Coal Conveyors.—The next details to consider are coal storage and coal-conveying gear, and there are various matters which must have the designer's attention.

(*a*) If the power house be situated in a position where coal is only infrequently delivered and where a plentiful supply must be kept, then the method of storage will depend on whether the available fuel is bituminous or anthracitic (i.e. whether it will lose its value by open storage or not) and whether the general climate is hot and dry, or hot and moist, or generally humid.

(*b*) Dependent on the above it will be determined whether to provide covered silos at ground level or below it, or whether this expense may be saved and the coal dumped on a paved storage ground in the open.

(*c*) The means of unloading, i.e. whether a wharf beside which ships may unload, or a railway siding, and the height and level of embankment with respect to the firing level.

(*d*) The overhead storage should be reduced to a reasonable limit, since the additional steel work for carrying the large weight is costly and usually unnecessary, except in special cases where sites are very expensive.

(*e*) Subdivision of storage and other bunkers, so that in the event of spontaneous combustion of coal the compartment can be rapidly emptied to prevent the fire from spreading. Means should be provided for ascertaining the temperature at the bottoms of the bunkers, e.g. by suitable thermometer pockets or shafts.

(*f*) Arrangement of bunkers to trim and empty automatically, remembering that the angle of repose of tipped small coal

is from 30° to 60° from the horizontal, depending on its quality and dryness.

(*g*) Adequate ventilation of all bunkers.

Unloading Coal from Ships.—In the case of large power houses a pier may be constructed as shown in Plate III. (p. 73), so that large steamers may lie alongside at all times of the tide. Or a wharf can be built to berth lighters and smaller ships, or even large cargo steamers in rarer cases where there is sufficient depth of water. Unloading may be effected either by electrically operated grabs or by a hopper directly feeding a conveyor. The coal may then be distributed by coal waggons into coal silos, as in the case of the Greenwich station of the London County Council, or by automatic tipping tray conveyors. Two cranes, each fitted with two motors, one of 50 H.P. for lifting and one of 10 H.P. for slewing, will unload 2000 tons in 24 hours. In some cases a Temperley transporter is used if the coal is distributed in the open, or if the run back from the wharf to the power house is at some distance or at a high level.

A description of a very complete unloading plant for a large power house at Buenos Ayres, shown in Fig. 30, may now be given.

Ocean-going colliers discharge the coal alongside the power house wharf, and the coaling plant delivers the coal into storage silos or direct into the overhead bunkers, as shown in Fig. 30, first passing the coal through suitable breakers. Travelling bridges are to be constructed, each with tipping tray conveyors to handle large coal. The bridges will accommodate 4½-ton tip cranes, each with a working radius of 35 feet, and capable of hoisting the maximum load at a speed of 100 feet per minute, and handling 50 tons per hour. The tray conveyors will transport 100 tons per hour, and will deliver the coal into breakers placed in towers at each end of the silos, so as to prepare the coal for use in the mechanical stokers. As the coal descends to the distributing conveyors it is automatically weighed and registered, and is then delivered through rotary fillers to either of two gravity bucket conveyors, which feed either into the silos or direct into the overhead bunkers; or from the silos to the bunkers, as may be required.

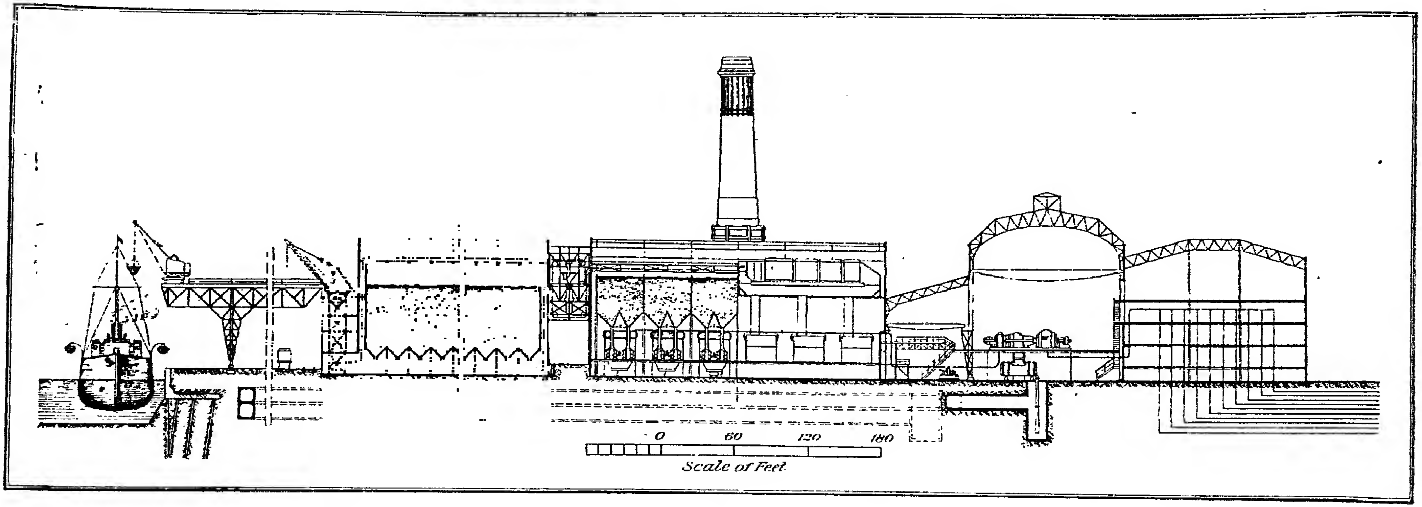


FIG. 30.

Unloading Rail-borne Coal.—In cases where coal is rail borne, the silos can be so arranged that the wagons can empty directly into the bunkers, approaching from the siding by a ramp, embankment, or viaduct. Where the conditions are such as to render silo storage unnecessary, then the wagons can discharge into a filling hopper from which the coal is taken by cross conveyors to the main conveyor. This represents the method adopted by the Author for the Bahia Blanca (Argentina) power house for the B.A. and Pacific Railway, as shown in Figs. 31 and 32. The capacity of the filling hopper and conveyor is 50 tons per hour. The coal passes through a coal crusher which, with the cross conveyor, is driven by a 20 B.H.P. squirrel cage 3-phase motor (565 R.P.M., 500 volts between phases). The cross conveyor feeds into one or other of the two main gravity bucket conveyors, each with a capacity of 50 tons per hour, and each driven by a 10 B.H.P. squirrel cage 3-phase motor (565 R.P.M.).

Silos.—If the coal is stored in a silo, the capacity of the latter must be sufficient to ensure the power house of a supply for a month or for a longer period, according to the regularity of the coal delivery. Allowance must also be made for contingencies, such as storm-bound ships, strikes, and so forth.

The silos may be constructed as shown in Plate III. which illustrates a coal store designed by Mr. John H. Rider for the Greenwich power house. In this case the silo has a capacity of 2000 tons and is built of ferro-concrete with bulkheads dividing the bunkers. These have self-trimming bottoms and mouthpieces with hand-operated valves feeding the coal into a filler, thence into gravity bucket conveyors, which in turn carry the coal to the overhead feeding bunkers. Each conveyor has a carrying capacity of 40 tons per hour, and is driven by a 25 B.H.P. squirrel cage 3-phase motor (475 R.P.M., 220 volts between phases). The weight of coal is checked on weigh bridges with 5-feet dials, which are accurate within 3 lbs. on a load of 5 tons.

Large bunkers should be served with a hydrant system, so that water may be available in the event of fire breaking out in any compartment. A water service is unnecessary for small

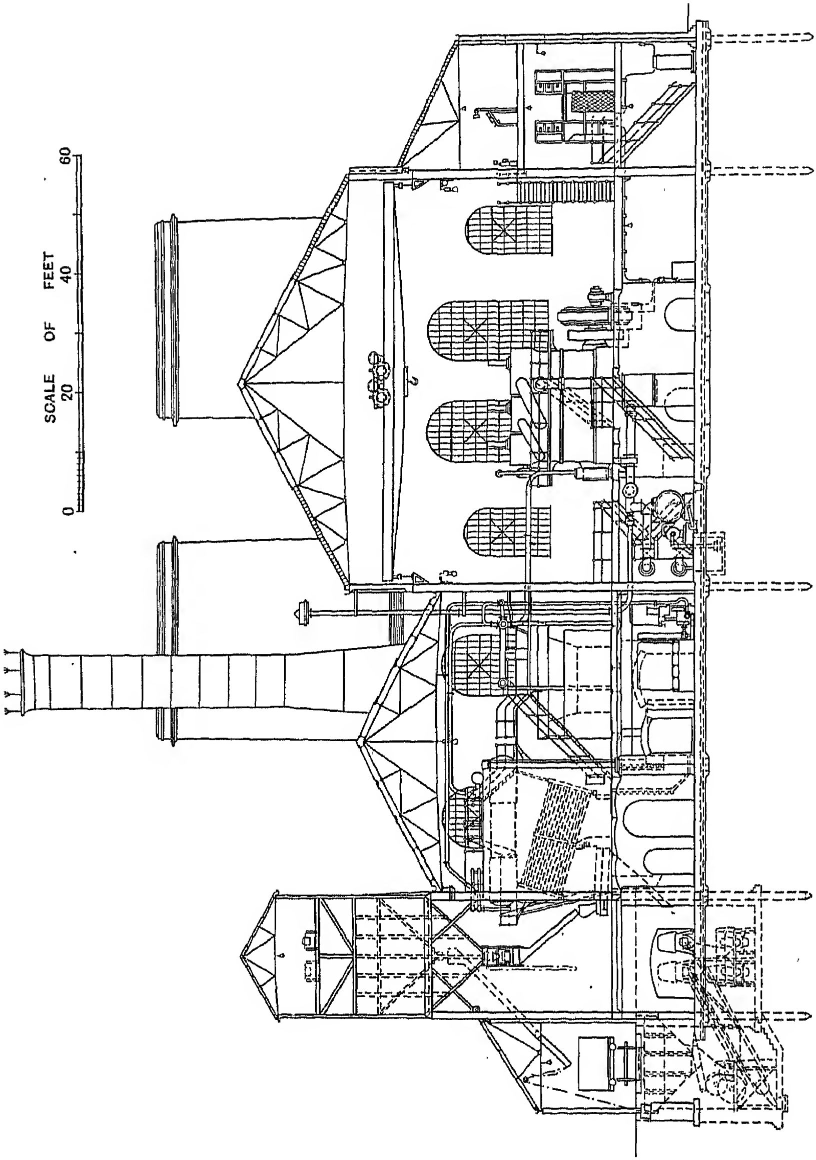


FIG. 31.

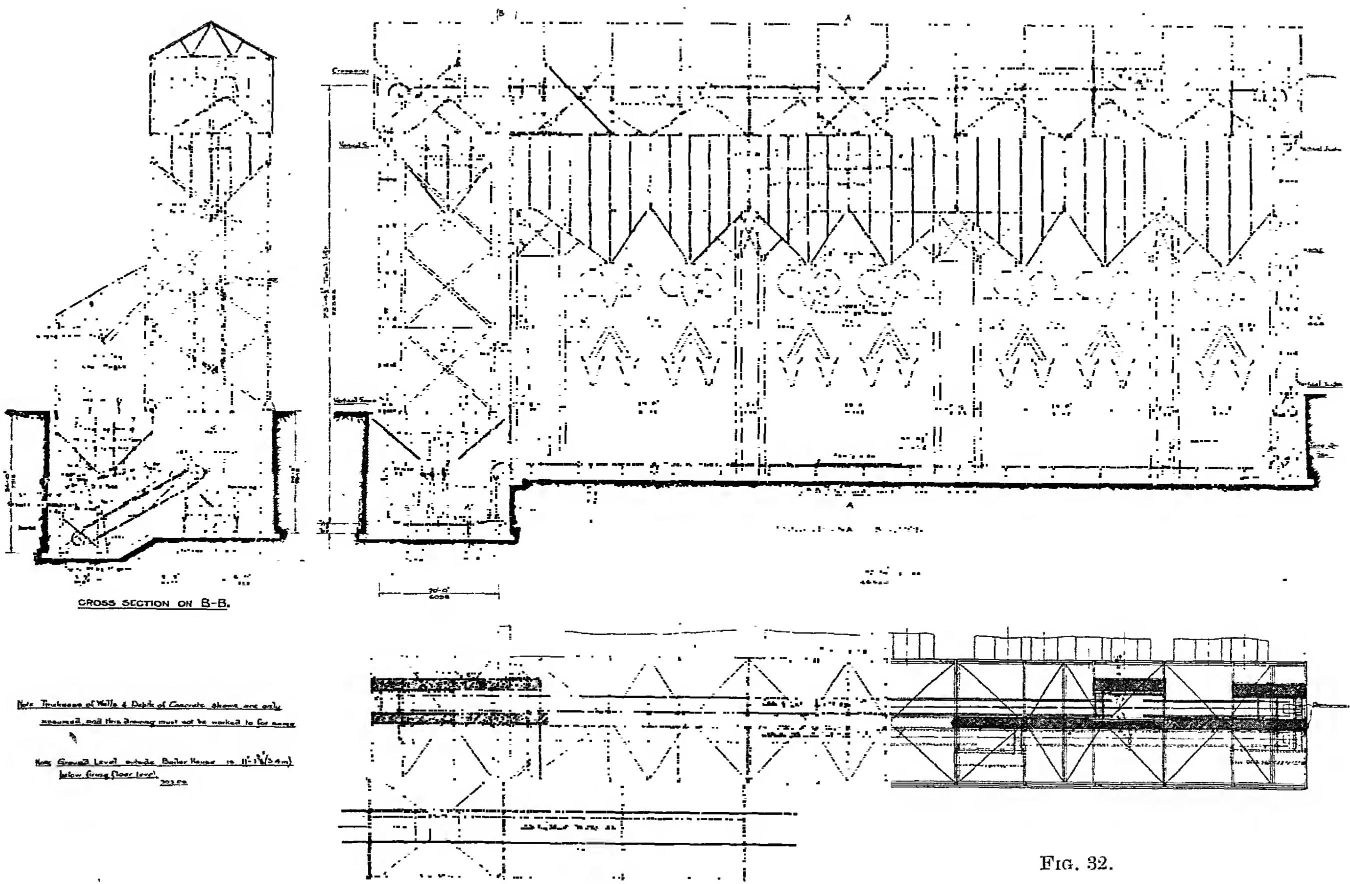

CROSS SECTION ON B-B.
Note Thickness of Walls & Depth of Concrete shown are only assumed, and this drawing must not be worked to for same
Note Ground Level outside Boiler House is 11'-3⅞" (3.4m) below firing floor level.

FIG. 32.

bunkers, which can more readily be emptied, and in which no coal remains for any length of time.

In some localities the expense of coal silos can be avoided by dumping the coal on a paved ground and thence distributing it by a transporter acting radially or running lengthwise, which not only unloads and trims the coal, but also picks up and discharges the coal into the regular conveyor. Such a transporter is shown in Fig. 33.

In very hot and moist climates it may be necessary to build underground storage bunkers, so as to obtain a more equable all-year-round temperature.

Adequate subdivision of the bunkers is necessary, as well as the provision of means for ascertaining the temperature of any stratum of the coal stored in them.

Overhead Bunkers.—Too large a storage overhead is costly on account of the stiffer steel work necessary, involving heavier stanchions and bracings. The function of overhead bunkers is not to store coal but to maintain a supply at such a level that it can gravitate to the stoker hoppers.

The storage of coal is another consideration altogether, and the capacity of the overhead bunkers should never be more than sufficient for three days' supply. The bunkers can be arranged one to each boiler, and should be designed for the above-mentioned supply on the basis of 40 cubic feet per ton. It will be found to be cheaper to build the bunkers as a continuous structure with bulkheads (which also act as stiffners) than to build separate bunkers. Figs. 31 and 32 show the arrangements of the overhead bunkers at the Bahia Blanca power house. These, of course, have self-trimming bottoms, with mouthpieces to which are attached automatic weighers recording in kilogrammes, and also in tons by the simple addition of a fixed weight to alter the calibration of the dials. Hinged chutes guide the coal from the bunkers to the stoker hoppers.

The pre-war cost of overhead bunkers complete with all accessories amounted to about £2 per ton of full capacity for coal storage.

Specification of Materials.—The following general specifica-

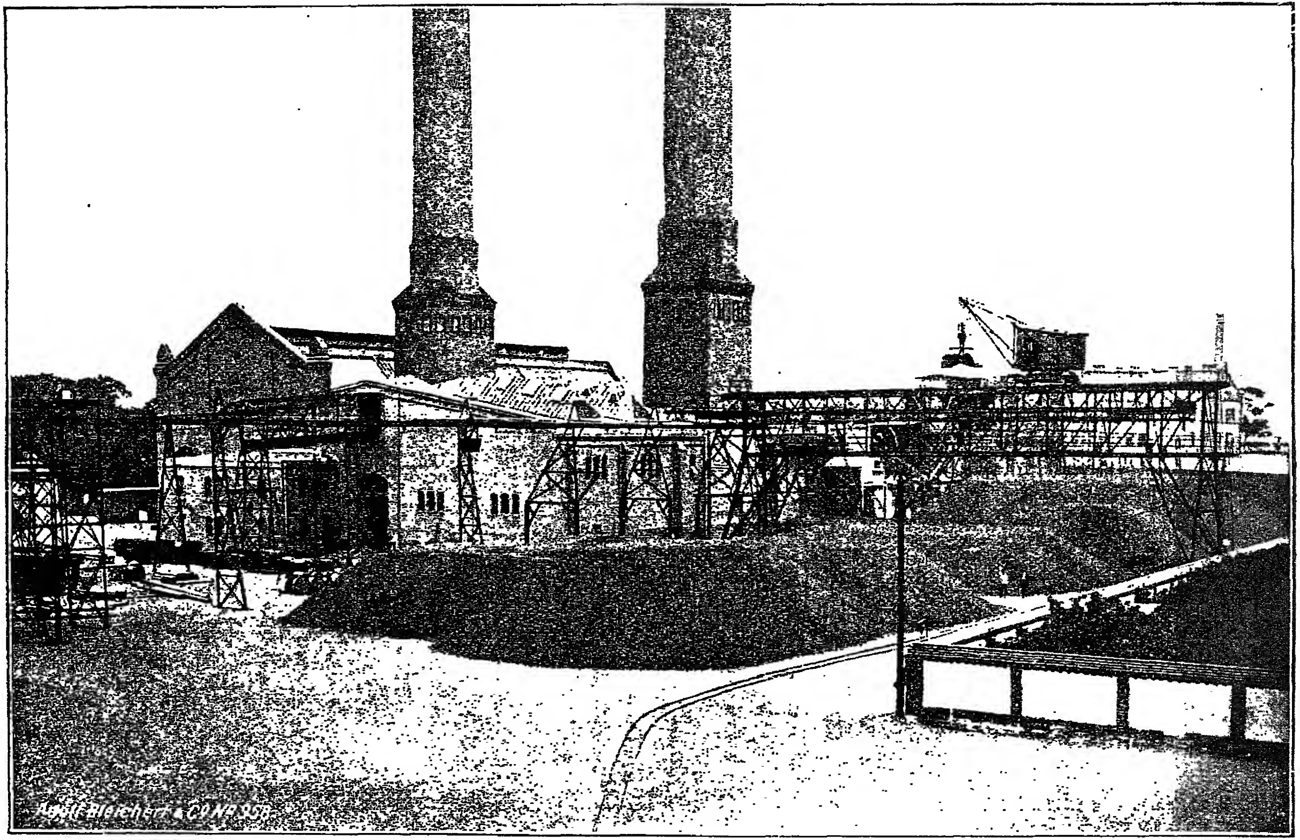


FIG. 33.

tion for the structural work of bunkers will be useful to the designer.

The overhead bunkers to be made of sheet steel to hold some determined quantity of coal (usually from 2 to 7 days' supply per boiler), based on a coal measurement of 40 cubic feet per ton.

The steel plates are usually $\frac{3}{8}$ inch in thickness, with angles and tee-bar stiffeners where necessary, shaped to suit the self-trimming angle of the particular coal, and terminating in hopper mouths fixed to the duplex cut-off valves.

All steel used to satisfy the following specification :—

Tensile strength, 26-30 tons per square inch.

Elongation to be not less than 20 per cent. in a test length of 8 inches.

The maximum working stress on any part of the bunker steel-work when fully loaded should not exceed 6 tons per square inch.

Transverse steel bracings and conveyor track and platform supports, as well as the necessary conveyor housing and roof, to be specified.

Gravity spouts to the stoker hoppers are usually of $\frac{3}{16}$-inch steel plate, counterweighted and swivelled so as to be swung out of the way.

Safety Devices for Conveyors.—In arranging the conveyors it should always be possible to shut down the conveyor motors from several points along the conveyor route, and safety pushes actuating the motor control switch should be fixed for this purpose. A pawl is always arranged to engage between the links of the chains to prevent the conveyor from running backwards when the motor stops. A further device may be adopted as arranged by Messrs. Spencer & Co., Ltd., of Melksham, England, to prevent the buckets and chains from falling in the event of breakage. Two continuous vertical runners are fixed as shown in Fig. 34; should the chain break it will only fall a few inches and then jam in the runners. A compensating carriage to take up the slack in the conveyor is always provided.

Economy of Coal-handling Plant.—Coal-handling plant is

almost generally used in large power stations, as the cost of mechanical handling is only $\frac{1}{5}$ that of hand firing in cases where labour charges are about the same as obtain in England. In districts, however, where native labour is cheap, the cost of coal-handling plant may sometimes be saved. The Steam Users' Association of New England states that one man can fire from 0·35 to 0·43 ton per hour at an *average* cost of 2s. or 48 cents per ton. This, however, does not include any cost of unloading, trimming or further handling of the coal between the point of discharge and the firing floor.

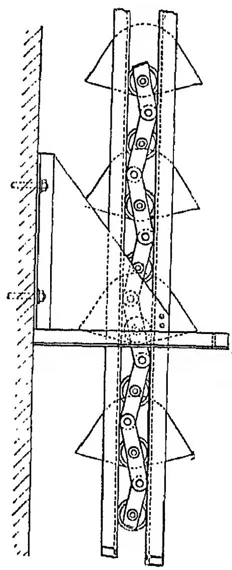


FIG. 34.

Coal-weighing Machines are supplied, usually of 2 cwt. capacity, complete with valves, operating gear, and recording counters registering each 2 cwt. charge.

The continuous weighing machine known as the Blake-Denison, shown in Fig. 35, can be applied to any form of conveyor, the weigher adjusting itself to any variation of load or speed with an accuracy within $\frac{1}{2}$ per cent. of the true load. This machine is self-recording, the net weights passed over it being read at any time. If 20 feet of the conveyor be taken as the weighing length, the machine registers every time a 20-foot length of conveyor passes, the weigher being driven by the conveyor itself.

Disposal of Ashes.—Owing to the large quantities of ashes handled in large power stations, it is practically necessary to fix mechanical plant and special appliances to deal with them. The main coal conveyors can be arranged to return through the ash gallery, as shown in Fig. 32, and convey the ashes and clinker to a conveniently placed ash bunker; this in turn empties into coal waggons or barges, as the case may be, by which the ashes are removed. The removal of ashes may prove to entail a heavy annual expenditure, and it will sometimes pay to arrange screens to subdivide the refuse. Part of

this can then be disposed of to builders and contractors at a price which in certain districts will be found to neutralize the cost of ash removal.

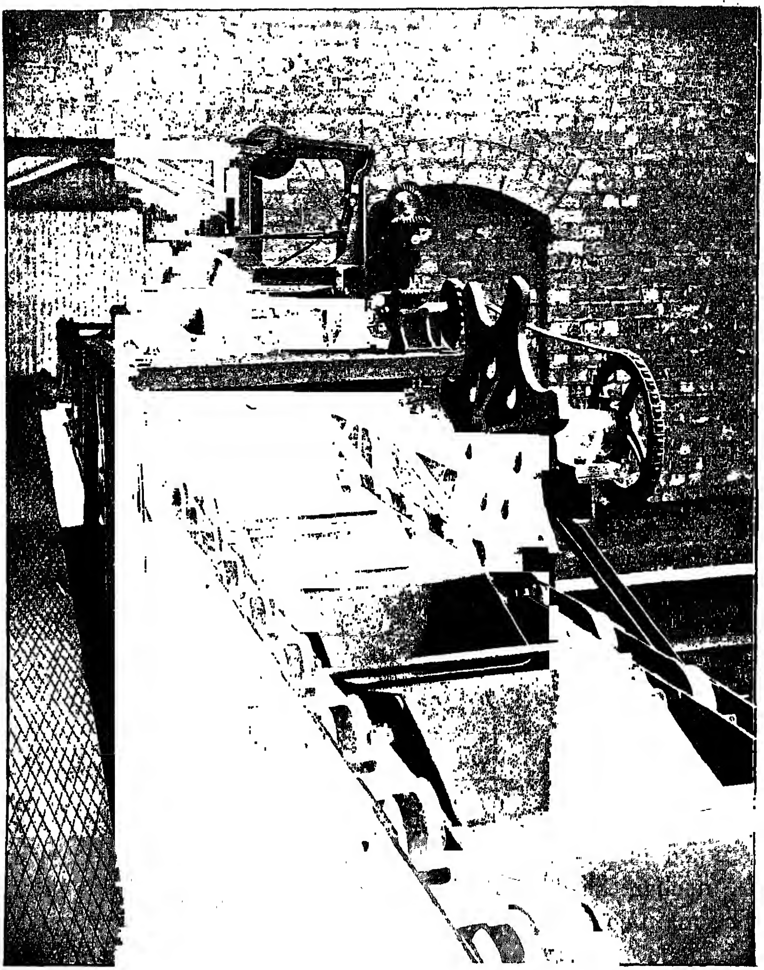


Fig. 35.

Ash bunkers are preferably made of reinforced concrete, owing to the corrosive action of the slaked ashes, and are usually based on a measurement of 50 cubic feet to the ton.

Oil-fired Boilers.—A brief reference is necessary to developments in the use of oil-fired boilers in power houses, and to the application of oil fuel to the firing of water-tube boilers. In the case of some power houses abroad where the cost of coal was excessive, the Author has been responsible for the conversion of coal-fired Babcock & Stirling boilers to oil-firing with very successful results.

The advantages of oil fuel as compared with coal, apart from the question of cost, are as under:—

(*a*) There is an increased boiler efficiency due to the complete combustion and to the heating surface being maintained in a clean condition free from soot.

(*b*) There is no wasteful cooling due to large volumes of air passing into the furnace as no fire-doors have to be opened.

(*c*) An equal distribution of heat can be maintained.

(*d*) A reduction in the cost of labour is obtained as firemen are not required, one man being able to regulate the burners of several boilers, and there are no ashes to handle.

(*e*) Reduced maintenance charges, there being no wear of grate bars, mechanical stoker parts, coal-conveying plant, etc.

(*f*) Greater cleanliness, there being no dust, clinker, or ashes to remove.

(*g*) Oil is stored more simply and easily than coal and requires less storage accommodation, namely, 39 cubic feet of storage space per ton as compared with 42 to 45 cubic feet in the case of coal.

(*h*) The oil tanks can be placed in the most suitable and safe position away from the power house, and have not to be rigidly fixed in juxtaposition to the boiler house as in the case of coal storage with coal-handling apparatus.

(*i*) The control of steam production is easier and more effectively and rapidly managed.

(*j*) The fires can be instantaneously ignited and extinguished.

Very high evaporation per square foot of boiler heating surface can be obtained; namely, as much as 18·7 lbs. per square foot at a rate of 15·3 lbs. of water from and at 212° Fahr. per pound of oil. These figures were recorded at the U.S. Naval oil

fuel testing plant, Philadelphia, with a Babcock & Wilcox boiler having a heating surface of 4000 square feet.

There are three systems used in applying oil fuel to the firing of boilers:—

(1) Oil burners with steam as a spraying agent. This is the simplest arrangement and is most commonly used in land practice. The steam required is from 2 to 5 per cent. of the total steam raised. The steam-assisted burner will deliver an average of 250 lbs. of oil per hour up to a maximum of 550 lbs.

(2) Burners in which compressed air is used for spraying and atomizing. Not so much used as the first and third systems.

(3) The pressure system, by which the oil is atomized mechanically. This gives the highest efficiency and highest rates of combustion. In the Babcock system, the oil is pumped through the burners at a high pressure, the stream of oil being made to rotate rapidly in passing through the burners. On emission, the centrifugal force breaks up the oil into a fine mist which is completely burned by a proper method of air mixing. An average delivery of 450 lbs. of oil per burner per hour can be maintained by this system with a maximum as high as 900 lbs.

The cost of installation of the pressure system is higher than that of the other two systems, owing to the auxiliary apparatus required which comprises a pressure oil pump with oil filters both in the suction and delivery ends, a heater to make the oil fluid, and a forced draught fan.

In the case of a power house abroad, the cost of an installation of three oil-firing sets on the pressure system, each pumping 6600 lbs. of liquid fuel per hour, and comprising oil fuel heaters, pumps, suction and delivery filters, distributing boxes, burners, suction and pressure pipes, valves and other fittings, and spare parts, amounted to £2800 f.o.b. a British port. This is equivalent to about £0·035 per 1000 lbs. of water evaporated per hour from and at 212° Fahr.

A general specification for oil-fired boiler fittings is as under:—

The oil fuel heaters are usually constructed with mild steel

bodies and solid drawn steel tubes expanded into mild steel tube plates.

The special furnace fronts are of mild steel with stiffeners and fixing bolts, and are lined with special non-conducting material.

Cast-iron air registers are fitted with specially shaped fire-bricks for lining, forming openings into the furnace for the oil and air to be sprayed in.

Cast-iron suction strainers with shut-off valves for cleaning.

Suction and delivery oil filters, two for each oil fuel heater.

Steam driven double-acting oil force pump running at about 40 double strokes per minute, with cast-iron plungers, steel rods, and fitted with air vessel, spring loaded relief valve, and suction and discharge valves.

Pressure gauges are inserted (1) in the pump discharge, (2) between the two sets of filters, and (3) in the discharge from the hot oil fuel filter.

In addition, there are required distributing valves to control each sprayer, as well as various shut-off valves, and pipework, and regulating air-register.

Generally speaking, it will pay to burn crude oil fuel, which has a calorific value of from 18,000 to 19,000 B.Th.U., when its cost does not exceed $1\frac{1}{2}$ times that of good steam coal (of 14,500 B.Th.U.), or $1\frac{3}{4}$ times that of bituminous coal (of 11,500 to 12,000 B.Th.U.).

Plate VI. shows a Babcock & Wilcox marine type boiler for land use, fitted for oil-firing, with the steam atomizer system described above. The arrangement of furnace chamber is the same when pressure burners are fitted in accordance with the third system.

Gas-fired Boilers.—Boilers both of the drum and water-tube types have been adapted for gas-firing at collieries, coke-oven works and waste heat stations, and good results have been obtained.

The use of gaseous fuel offers many of the advantages referred to in connection with oil-firing, and thermal efficiencies of about 70 per cent. have been secured with water-tube boilers (without economiser) when using gases of a high calorific

value, such as coke-oven gas (500 to 550 B.Th.U.). With gases, like producer gas or blast furnace gas, of considerably lower calorific value, the thermal efficiency decreases and the heating surface of the boiler must be increased to obtain the same evaporation. In order to obtain the best results, it is important that the supply of gaseous fuel should be at a constant pressure in order to facilitate the regulation of the air supply.

The following results of a series of tests with a water-tube gas-fired boiler may be quoted. The fuel employed was producer gas obtained from an ammonia recovery producer, and its calorific value ranged from 128 to 135 B.Th.U. per cubic foot. Steam was raised at a gauge pressure of 120 lbs. per square inch, and the actual evaporation per square foot of heating surface per hour varied from 2·9 to 3·2 lbs. of water. The equivalent evaporations from and at 212° Fahr. varied from 3·5 to 4 lbs. of water.

The problem of gas-firing is one that will undoubtedly repay further investigation as is apparent from the promising results already obtained by the application of the principle of surface combustion to fire-tube boilers of the shell type. Such boilers, for which thermal efficiencies as high as 90 per cent. are claimed, have already been constructed for moderate outputs and steam pressures. The experience gained in their use should provide a basis for the design of high pressure high efficiency gas-fired boilers suitable for the requirements of large power houses.

Feed Water and Water Softening.—In modern power houses it is almost general to use condensers; with turbines, of course, they are indispensable. Thus the only fresh feed water required is the "make-up" addition to the air-pump discharge to the hot well. Most waters will require some chemical treatment, and the air-pump discharge in reciprocating engine power houses must be treated for the removal of oil. Apparatus for both purposes may properly be dealt with under this section as auxiliary to steam-raising plant.

Taking first the feed water itself. This may be obtained from the public supply, from a well on the power house site, or from the river on the bank of which the power house is placed.

Such waters may sometimes possess acidic properties, but more usually contain the soluble salts of calcium and magnesium, especially when derived from deep-seated wells. There may be vegetable acids present when water is obtained from a peaty or marshy source.

The acidic ingredients cause corrosion and pitting of the boiler plates and tubes, and electro-chemical action between the gun-metal fittings and the steel seatings, and such waters, though curable, are to be avoided.

Feed waters may be described as hard or soft, according to their behaviour with soap. Hard water contains lime and magnesia salts which decompose soap to form calcium or magnesium stearates. Before a lather can be obtained in a soap test, the whole of the lime and magnesia salts present in solution must be converted into insoluble stearates. Boiling partially softens the water by driving out the carbonic acid gas and causing precipitation of the carbonates of calcium and magnesium. The sulphates often to be found in certain waters can only be expelled by chemical means or by raising the water to a high temperature. Some salts are more soluble in cold than in hot water, and most lime salts are deposited at a temperature of about 300° Fahr.

The following table gives the solubilities of scale-forming materials, the figures being derived from Landolt and Börnstein's Physical and Chemical Tables (4th Edition, 1912) :—

TABLE XXVII.

SOLUBILITIES OF SCALE-FORMING MATERIALS.

Salt.	Solubilities.		
	Temperature deg. C.	Parts of salt in 100 parts of solution (by weight).	Parts of solution containing one part of salt (by weight).
Calcium carbonate ($CaCO_3$) . .	16°	0·0013	76,923
Calcium phosphate ($CaHPO_4$, $2H_2O$)	24·5°	0·02	5,000
Calcium sulphate ($CaSO_4$, $2H_2O$) .	18°	0·2016	496
Magnesium carbonate ($MgCO_3$, $3H_2O$)	12°	0·097	1,031

The designer will, of course, ascertain whether water is obtainable on the site from an artesian well, or from a well from which the water has to be pumped. In any case, whether this be so or not, an analysis of the water must be taken whatever the source. If from a river, then analyses during ordinary flow, drought, and storm freshets should be made. According to the analyses he will know whether to adopt a simple cold water treatment or whether a hot treatment will be necessary.

One principle must be observed, that is, to precipitate as much as possible of the scale-forming matters in solution and suspension before the water enters the boilers. Approximately 10 to 15 per cent. better evaporation per pound of coal will be obtained in a clean boiler as compared with one having a small deposit of scale; moreover the saving in cleaning and repairs is very appreciable, and an increased boiler life is obtained. Scale $\frac{1}{64}$ inch in thickness causes a loss of some 2 per cent. of the fuel burnt; scale $\frac{1}{32}$ inch, 4 per cent.; and scale $\frac{1}{16}$ inch, 9 or 10 per cent.

Exhaust Steam Heaters.—It is a barbarous practice to reduce the thermal efficiency of the boilers and run the risk of pitting and corrosion by the introduction of alkaline reagents in the boiler itself, and in land practice such an out-of-date method can and should be avoided. Feed-water heaters are sometimes introduced, through which the exhaust steam from the feed pumps and other auxiliaries is made to pass. The heater raises the feed water to a temperature approaching boiling point, expels the carbonic acid gas absorbed by the water, and, by the aid of reagents, causes the removal of all solids from the feed water. Where the water contains a comparatively large proportion of magnesic or calcic sulphates such a heater is probably advisable. Where, however, the water contains only carbonates, it may be treated by a cold process. The reagents usually required (according to the analysis of the particular water) are either milk of lime with caustic soda, soda ash, fluoride of soda, or aluminate of soda.

Water Softeners.—There are many systems of water softening which have their peculiar advantages in the detail of the apparatus. For example, there is the "permutit" process which

destroys the hardness of water—whether temporary or permanent—without involving the precipitation and subsequent removal of any scale-forming solids contained in the water. Softening is effected by the chemical action of a filtering bed of zeolytic material through which the impure water is passed, the metallic base (sodium) in the zeolite being exchanged with the metallic bases (calcium and magnesium) of the scale-forming salts. The "permutit" thus fixes the calcium and magnesium, thereby gradually losing its activity, and the water which passes on contains freely soluble sodium salts, such as the carbonate or sulphate according to the original quality of the water. The process can be used with cold water, and the spent "permutit" is regenerated by treatment in a separate tank with a weak solution of common salt. The sodium base of the zeolytic mass is thus replaced, and the calcium and magnesium bases pass into solution in the form of freely soluble chlorides. The apparatus required is of a simple kind, and the labour costs are less than those of processes requiring the mixing and injection of reagents and the subsequent filtration of precipitated solids. In considering the adoption of the process at any power station, regard must of course be given to the relative local costs of the "permutit" material and of the reagents, such as lime or soda, required for other water-softening processes. It may sometimes prove advantageous to treat water having temporary hardness by means of an ordinary reagent process as a first stage, and then to follow with a treatment by the "permutit" process.

The Author's experience of several kinds of water softeners leads him to suggest that the type involving a simple reagent tank and a larger precipitation tank with a steam injector and ejector, the one for "boiling" the reagents introduced, and the other for taking up the reagents so mixed and injecting them into the water to be treated, is the simplest and least expensive to maintain. Where large and somewhat complicated precipitation tanks are used, the additional difficulties of cleaning, and the cost of repair, become a nuisance in a power house, where simplicity and ease of examination and repair should be made axiomatic.

The location of this apparatus should be either in the

boiler house or boiler-house basement, or in the pump-room annexe.

Capital Cost of Water-softening Plant.—The cost of water-softening plant before the war was approximately as follows (based upon a plant load factor of 25 per cent.) :—

TABLE XXVIII.

CAPITAL COST OF WATER SOFTENING PLANT.

Size of power house.	Cost per K.W. installed (Pre-war.)	
	Hot process.	Cold process.
	£	£
1,000 K.W.	0·18	0·195
2,000 ,, ...	0·145	0·160
5,000 ,, ...	0·100	0·114
10,000 ,, ...	0·082	0·089
20,000 ,, and upwards . .	0·064	0·073

The cost of treatment obviously varies with the class of water; but, speaking in general terms, in the Author's experience a moderately hard water could, before the war, be softened to 5 per cent. by Clark's scale (i.e. one degree of hardness represents one grain of calcium carbonate per gallon) for 0·6d. (1·2 cents) per 1000 gallons treated.

Since the feed "make up" to cover leakages, blow down, drains, etc., in a condensing power house may be taken as approximately 10 per cent. of the water evaporated, it is easy to estimate the annual cost for any given power house.

Apparatus to Test Hardness of Water.—A hardness testing apparatus is a necessary part of the equipment. This is a very simple affair, merely consisting of a burette calibrated in cubic centimetres, and some bottles of soap solution. A definite quantity of the water to be treated having been introduced into the burette, a quantity of soap solution is added and the tube shaken until a permanent lather is obtained. The proportion of added solution, by reference to a well-known table, will give the hardness of water by Clark's scale.

There are other methods of testing the hardness of water; for example an electrical resistance method, as designed by Mr. W. P. Digby, which is extremely simple in its operation and has been found accurate within 1 per cent.

Oil Elimination Plant.—As stated above, another auxiliary must be adopted with reciprocating engine equipments, viz. a chemical precipitant for the oil brought over by the exhaust steam. Incidentally, it should be mentioned that much of this should be extracted between the engine exhaust and the surface condenser by a separator, so as to avoid clogging or impairing the value of the condenser tubes. The water then discharged by the condenser wet pump is led into a mixing tank, part being shunted into a reagent tank, which can be kept charged with a mixture of chemicals of a fixed strength. The proportion of water shunted into the reagent tank causes an equal displacement of reagents, which are thus automatically adjusted to the flow of water at any time from the condenser pump. The reagent (alumino-ferric and soda ash) causes the oil in the water to become coagulated or jelly-like. By passage through suitable filter tanks containing wood-wool, or quartz sand, the oil is precipitated, and the resultant water is quite pure and ready for use again in the boilers. It is, in fact, pure distilled water.

In the Davis-Perrett oil elimination plant no chemicals whatever are used, electricity being employed to effect the separation of the oil from the water.

The air-pump discharge is delivered into a wooden treating tank, provided with a separate compartment into which the oily water first flows. The water then leaves this compartment and flows through other compartments of the tank, in which metallic electrodes are placed. These are arranged so as to cause the water to circulate between them in a circuitous path. During its passage, the water is subjected to the action of an electric current, the emulsive character of the oily water being completely destroyed and the oil forming a flocculent precipitate, which is easily removed by a sand filter (see Fig. 36).

The plates in the treating tank are kept clean by reversing their polarity with a change-over switch, actuated about once in 24 hours. When the plates on one pole become foul the

reversal of the current causes the oil to leave the plates and to rise to the surface as a scum.

In order to regulate the amount of current proportionately to the quantity of water required to be treated, a small amount of tap water is allowed to flow into the treating tank with the

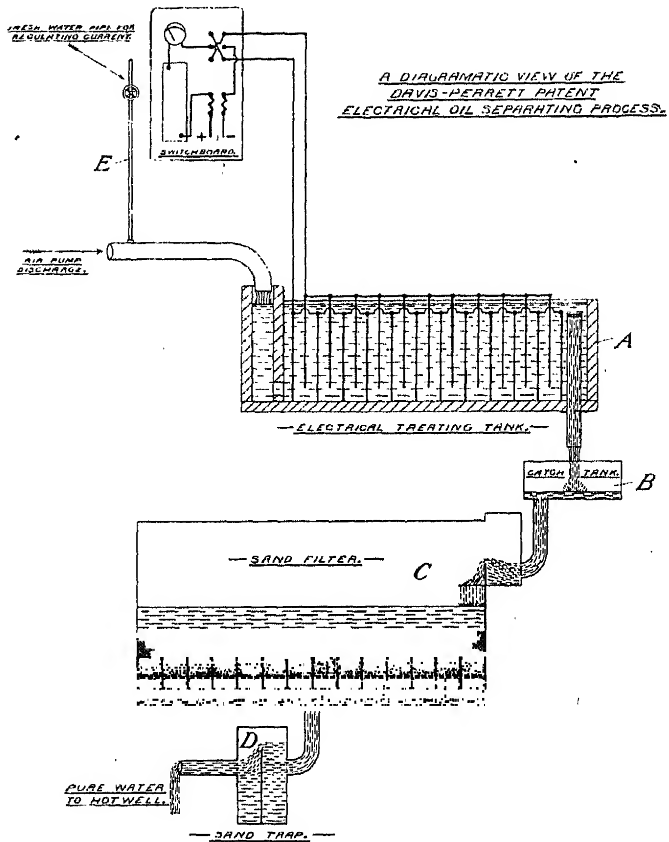


FIG. 36.

oily water, thereby altering the ohmic resistance of the solution in the treating tank.

The apparatus is usually designed so that the tanks take one unit per thousand gallons of water treated. The feed water can be treated at a temperature as high as desired, viz. 130° to 140°

Fahr. or even higher. It is advisable in every case that the temperature should not be below 100° Fahr. for the sake of economy.

The purity of the water after treatment is found to be such that less than 0·1 of a grain of oil remains per gallon of water.

Table No. XXIX. gives the floor space and head room occupied by apparatus of various capacities.

TABLE XXIX.

ELECTRICAL OIL-SEPARATING PLANT.

Capacity. Gallons per hour.	Floor space in square feet.	Height from floor level. Feet.
1000	20	15
2000	40	15
4000	80	16
5000	100	20

Cost of Oil Elimination Plant.—The pre-war cost of the ordinary chemical apparatus for eliminating oil was as follows (based upon a plant load factor of 25 per cent.) :—

TABLE XXX.

CAPITAL COST OF OIL ELIMINATION PLANT.

Size of power house. K.W.	Pre-war cost of de-oiling plant. £ per K.W.
1,000	0·15
2,500	0·102
5,000	0·086
10,000	0·078

The cost of de-oiling treatment before the war could be taken at approximately ¼d. (0·5 cent) per 1000 gallons treated.

The apparatus is, of course, not required with turbines.

Economy of Feed-water Heating.—A great thermal advantage is obtained from heating feed water. With a boiler pressure of 180 lbs., the steam temperature will be 379° Fahr.; and if the temperature of the feed water is 60° Fahr., then 319 heat units

per pound of water must be added to raise it to the steam temperature. As 1168 heat units are required to evaporate 1 lb. of water at 60° to steam of 180 lbs. gauge pressure, a gain of 27 per cent. would be effected by heating the water to 379° Fahr. The water cannot, in practice, be raised to this temperature, but by exhaust steam heaters in small non-condensing plants the temperature may be raised to about 200°, giving a gain of some 12 per cent. In condensing stations with economisers, a temperature of 280° may be reached, thus giving a gain of about 18½ per cent.

A further economy may be gained by drawing live steam from an intermediate stage of a turbine and passing this steam through a second feed-water heater, thereby raising the temperature of the feed water more nearly to that of the steam in the boiler. For the higher steam temperatures and boiler pressures now generally used in the larger power houses, this economy cannot be neglected, especially in cases where the station load factor has a high value.

The following Table No. XXXI. can be used as a reference to find the percentage saving through heating the feed water (the boiler pressure being taken at 160 lbs. by gauge).

TABLE XXXI.

Thermal Economy of Feed-water Heating.

Initial temperature of feed water.	Final temperature of feed water and percentage thermal economy for boiler pressure of 160 lbs.					Initial temperature of feed water.
Degrees F.	160° F.	180° F.	200° F.	250° F.	300° F.	Degrees C.
	per cent.	per cent.	per cent.	per cent.	per cent.	
50	9·34	11·04	12·74	16·99	21·24	10
55	8·96	10·66	12·37	16·64	20·90	12·8
60	8·57	10·28	11·99	16·28	20·56	15·6
65	8·17	9·90	11·62	15·92	20·22	18·3
70	7·78	9·51	11·23	15·56	19·88	21·1
75	7·38	9·11	10·85	15·18	19·53	23·9
80	6·97	8·71	10·46	14·82	19·18	26·7

The figures given in the abové table apply to power houses where economisers are not employed for heating the feed water. The initial temperature of the water entering economisers

should never be less than 100° Fahr., and the percentage thermal economies for different boiler pressures due to the heating of feed water in economisers are given by Messrs. E. Green & Sons, Ltd., as in Table No. XXXII.

TABLE XXXII.

THERMAL ECONOMY OF FEED-WATER HEATING IN ECONOMISERS.

Rise in temperature of feed water. (Initial temperature 100° F.)	Boiler pressures and percentage saving of fuel or percentage increase in evaporation.					
	100 lbs.	150 lbs.	200 lbs.	250 lbs.	300 lbs.	350 lbs.
Rise of	per cent.	per cent.	per cent.	per cent.	per cent.	per cent.
100° F	8·95	8·88	8·83	8·79	8·76	8·72
110° ,,	9·84	9·77	9·71	9·67	9·64	9·60
120° ,,	10·74	10·66	10·60	10·55	10·51	10·46
130° ,,	11·64	11·54	11·48	11·43	11·38	11·34
140° ,,	12·53	12·43	12·37	12·31	12·25	12·20
150° ,,	13·42	13·32	13·25	13·19	13·13	13·08
160° ,,	14·32	14·21	14·13	14·06	14·01	13·95
170° ,,	15·21	15·10	15·01	14·94	14·88	14·82
180° ,,	16·11	15·98	15·90	15·82	15·76	15·70
190° ,,	17·00	16·87	16·78	16·70	16·64	16·57

NOTE.—The above figures do not include economy due to increased boiler efficiency. In certain cases this may amount to an extra 2 per cent. or more.

Economisers.—Economisers are necessary auxiliaries in power houses for utilising some of the heat otherwise wasted in the exit gases from the boilers and thus obtaining maximum thermal efficiencies. In an economically arranged boiler range, the temperature of the exit gases is from 425° Fahr. to 500° Fahr., usually approaching the latter figure, and the heat transmission through economiser tubes depends upon the temperature and also upon the velocity of the exit gases. For low temperatures and low velocities, the heat transmission falls as low as 2 B.Th.U. per square foot of tube surface per degree of difference between the mean temperature of the water in the economiser and that of the gases outside the tubes. For high temperatures and high velocity gases, the figure rises as high as 4·2 B.Th.U.

In smaller stations employing natural draught, an economiser is not of very material value unless the gases on leaving the

boilers incline to the higher limit of temperature. Where mechanical draught is provided, as is more usual in larger power houses, then the fullest use of the heat can only be made by inserting economisers between the boilers and shaft.

An economiser is usually made up of vertical water tubes with connecting end boxes and is inserted in the flue. The tubes are provided with automatic scrapers to prevent deposits of soot. The type known as Green's economiser contains all the essentials of an excellent design, embodies the automatic tube-scraping process, and is made so as to afford easy access to the tubes for inspection and cleaning and for cutting out old and fitting new tubes. The tubes of this economiser are always arranged in "nests". Expansion fittings connect the adjacent nests of tubes, and safety valves and blow-down or sludge valves are also provided.

The inlet feed water should always be admitted at a temperature of not less than 100° Fahr., to prevent sweating in the first rows of tubes and their consequent corrosion. This is easily arranged in condensing stations, since the hot-well water can always be expected to have a temperature of over 100° Fahr.; or some 90° Fahr., after the treatment for elimination of oil in the special apparatus for that purpose. In the rarer cases of non-condensing plants the temperature should be raised by exhaust feed heaters, in which the steam from the main engines and auxiliaries—or from some of them—is led through suitably arranged feed-water heaters.

Size of Economisers.—The leading particulars of standard sizes of Green's economiser are set out in Table No. XXXIII.

The following rules for the determination of economiser sizes should be followed:—

(*a*) The capacity of the economiser should be such that the feed water pumped through should be changed once in every hour. In the Green's economiser the standard capacity of each tube is 6¼ gallons, so that the number of tubes may be determined by dividing the rated evaporation of the boilers in gallons per hour by 6¼.

(*b*) On account of the scraper gearing details the number of tubes must be increased or decreased by not less than four

TABLE XXXIII.

GREEN'S ECONOMISER (SIZES AND CAPACITIES).

Number of tubes.	Number of tubes in width.	Number of sections.	Length of economiser.	Height over		Dimensions inside walls.			Free area for gases between tubes.			Capacity in pounds of water.	Internal heating surface.
				Gearing.	Sections.	Without deflectors.	With deflectors at back.	With deflectors back and front.	Without deflectors.	With deflectors at back.	With deflectors back and front.		
			ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	sq. ft.	sq. ft.	sq. ft.	lbs.	sq. ft.
96	6	16	9 8	13 6	10 2¼	4 8	5 5	—	21·5	28·5	36·25	6,000	960
120	6	20	12 1	13 6	10 2¼	4 8	5 5	—	21·5	28·5	36·25	7,500	1,200
144	6	24	14 6	13 6	10 2¼	4 8	5 5	—	21·5	28·5	36·25	9,000	1,440
168	6	28	16 11	13 6	10 2¼	4 8	5 5	—	21·5	28·5	36·25	10,500	1,680
192	6	32	19 4	13 6	10 2¼	4 8	5 5	6 4	21·5	28·5	36·25	12,000	1,920
216	6	36	21 9	13 6	10 2¼	4 8	5 5	6 4	21·5	28·5	36·25	13,500	2,160
240	6	40	24 2	13 6	10 2¼	4 8	5 5	6 4	21·5	28·5	36·25	15,000	2,400
64	8	8	4 10	13 6	10 2¼	6 0	6 9	—	26·5	33·5	41·25	4,000	640
96	8	12	7 3	13 6	10 2¼	6 0	6 9	—	26·5	33·5	41·25	6,000	960
128	8	16	9 8	13 6	10 2¼	6 0	6 9	—	26·5	33·5	41·25	8,000	1,280
160	8	20	12 1	13 6	10 2¼	6 0	6 9	—	26·5	33·5	41·25	10,000	1,600
192	8	24	14 6	13 6	10 2¼	6 0	6 9	—	26·5	33·5	41·25	12,000	1,920
224	8	28	16 11	13 6	10 2¼	6 0	6 9	—	26·5	33·5	41·25	14,000	2,240
256	8	32	19 4	13 6	10 2¼	6 0	6 9	7 8	26·5	33·5	41·25	16,000	2,560
288	8	36	21 9	13 6	10 2¼	6 0	6 9	7 8	26·5	33·5	41·25	18,000	2,880
320	8	40	24 2	13 6	10 2¼	6 0	6 9	7 8	26·5	33·5	41·25	20,000	3,200
352	8	44	26 7	13 6	10 2¼	6 0	6 9	7 8	26·5	33·5	41·25	22,000	3,520
384	8	48	29 0	13 6	10 2¼	6 0	6 9	7 8	26·5	33·5	41·25	24,000	3,840
416	8	52	31 5	13 6	10 2¼	6 0	6 9	7 8	26·5	33·5	41·25	26,000	4,160
448	8	56	33 10	13 6	10 2¼	6 0	6 9	7 8	26·5	33·5	41·25	28,000	4,480
480	8	60	36 3	13 6	10 2¼	6 0	6 9	7 8	26·5	33·5	41·25	30,000	4,800
512	8	64	38 8	13 6	10 2¼	6 0	6 9	7 8	26·5	33·5	41·25	32,000	5,120
544	8	68	41 1	13 6	10 2¼	6 0	6 9	7 8	26·5	33·5	41·25	34,000	5,440
576	8	72	43 6	13 6	10 2¼	6 0	6 9	7 8	26·5	33·5	41·25	36,000	5,760
80	10	8	4 10	13 6	10 2¼	7 4	8 1	—	31·5	38·5	46·5	5,000	800
120	10	12	7 3	13 6	10 2¼	7 4	8 1	—	31·5	38·5	46·5	7,500	1,200
160	10	16	9 8	13 6	10 2¼	7 4	8 1	—	31·5	38·5	46·5	10,000	1,600
200	10	20	12 1	13 6	10 2¼	7 4	8 1	—	31·5	38·5	46·5	12,500	2,000
240	10	24	14 6	13 6	10 2¼	7 4	8 1	—	31·5	38·5	46·5	15,000	2,400
280	10	28	16 11	13 6	10 2¼	7 4	8 1	—	31·5	38·5	46·5	17,500	2,800
320	10	32	19 4	13 6	10 2¼	7 4	8 1	9 0	31·5	38·5	46·5	20,000	3,200
360	10	36	21 9	13 6	10 2¼	7 4	8 1	9 0	31·5	38·5	46·5	22,500	3,600
400	10	40	24 2	13 6	10 2¼	7 4	8 1	9 0	31·5	38·5	46·5	25,000	4,000
440	10	44	26 7	13 6	10 2¼	7 4	8 1	9 0	31·5	38·5	46·5	27,500	4,400
480	10	48	29 0	13 6	10 2¼	7 4	8 1	9 0	31·5	38·5	46·5	30,000	4,800
520	10	52	31 5	13 6	10 2¼	7 4	8 1	9 0	31·5	38·5	46·5	32,500	5,200
560	10	56	33 10	13 6	10 2¼	7 4	8 1	9 0	31·5	38·5	46·5	35,000	5,600
600	10	60	36 3	13 6	10 2¼	7 4	8 1	9 0	31·5	38·5	46·5	37,500	6,000
640	10	64	38 8	13 6	10 2¼	7 4	8 1	9 0	31·5	38·5	46·5	40,000	6,400
680	10	68	41 1	13 6	10 2¼	7 4	8 1	9 0	31·5	38·5	46·5	42,500	6,800
720	10	72	43 6	13 6	10 2¼	7 4	8 1	9 0	31·5	38·5	46·5	45,000	7,200
760	10	76	45 11	13 6	10 2¼	7 4	8 1	9 0	31·5	38·5	46·5	47,500	7,600
800	10	80	48 4	13 6	10 2¼	7 4	8 1	9 0	31·5	38·5	46·5	50,000	8,000

sections, e.g. if the economiser is six tubes in width, the alteration of size must be twenty-four tubes, or if ten tubes in width, then the steps must be forty tubes.

(*c*) In arranging an economiser setting, care must be exercised to provide a sufficient area of flue, and in the disposition of the tubes. On the one hand, the gases must not be unduly throttled; and on the other, there must be adequate time for the gases flowing past the tubes to yield up sufficient heat units to raise the feed water to a reasonable temperature.

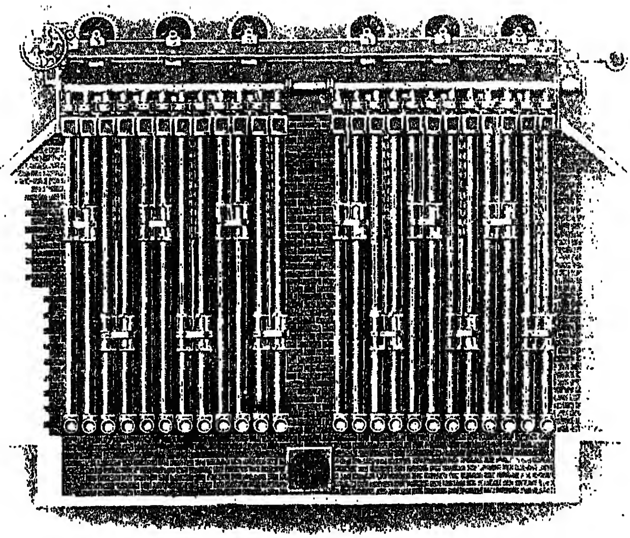
(*d*) The economiser must be set up so as to allow a space (usually 2 feet 6 inches in depth) underneath the lower boxes for the accumulation of soot. Soot doors are arranged at the sides of the brickwork setting for the withdrawal of this soot. Proper access must be allowed beside the economiser for the insertion of rakes to enable the soot to be withdrawn, and for barrows.

The internal linings are, of course, of firebrick bonded into the stockwork, as described in the paragraph on flues, and the end covers are usually of fire lumps, or quarles, carried on light angle irons or tees, as shown in Fig. 37. Deflectors are fitted at intervals to control the direction of the gases to the best advantage and to prevent short-circuiting the gases through the side alleys.

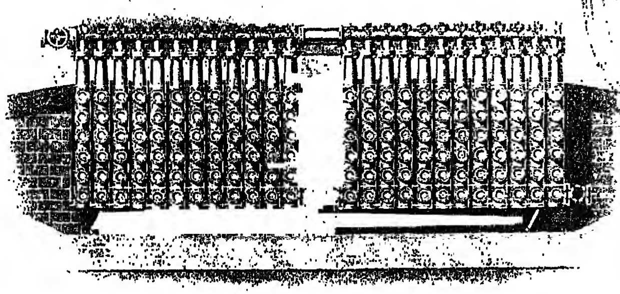
Control dampers are arranged at both ends of every economiser setting, so as to isolate the economiser from the flue.

Large economisers are occasionally subdivided by a firebrick mid-feather, thus enabling one half to be in use while the other is under examination or being cleaned out. To save space, economisers are usually fixed above the main bye-pass flue, and it is important that the arrangement should be such that the gases on leaving the boilers enter and leave the economiser for the shaft with a continual upward tendency, and not up and down or in a tortuous passage to the shaft as is sometimes found to be the case. In the Greenwich power house, for example (Plate III.), the economisers are fixed on a platform above the boilers. Such an arrangement reduces the width of the boiler house, and as the path of the gases is always upwards to the chimney it is an efficient system to adopt.

Cost of Economisers.—The pre-war cost of economisers erected complete but without brickwork was approximately



Elevation.



Plan.

Fig. 37.

£0·28 per K.W. of plant served, or £14 per 1000 lbs. normal evaporation of boilers.

Economiser Spares.—The usual accompaniment of tools and spares for an economiser outfit is as follows:—

Spare tubes: spare top and bottom headers: spare parts for scraper gear, scrapers and chains: spare lids for tubes, and a complete outfit for removal of tubes. Every economiser must be provided with a pressure gauge, thermometer and pockets for the measurement of the inlet and outlet feed-water temperature, and suitable tubes should be let into the brickwork for the insertion of pyrometers to measure the gas temperature before entering and after leaving the economiser.

Interchangeability of similar parts should always be insisted upon.

Feed Pumps may either be motor- or steam-driven. There is much to be said for a combination of both types. There is also something to be said for keeping the boiler-house system intact and independent of the electrical system in the event of any interruption of supply. Of course, electrical pumps can be supplied from the independent exciters where these are used, and the more reliably in cases where there is also an auxiliary battery.

The Author, however, inclines to the use of steam-feed pumps alone because (*a*) they are less expensive in capital cost than the motor-driven pumps; (*b*) the commercial efficiency of the modern high-class pump is very high; (*c*) they are more easily regulated over wide ranges of delivery and the exhaust steam is useful for feed-water heating.

A large high-class compound pump will easily deliver 110 lbs. of feed water per lb. of steam against the boiler pressure through a moderate and well-designed feed-water pipe system. In other words, a steam feed pump requires something less than 1 per cent. of the steam raised to deliver the necessary amount of feed water. Simple steam pumps will deliver some 75 to 85 lbs. of feed water per lb. of steam used.

Where steam feed pumps are adopted they should always be supplied from a donkey steam pipe, so that the pumps can be supplied independently of the main steam range. Both duplicate steam pipes and duplicate feed suction and delivery pipes are indispensable.

Details of Feed Pumps.—The following practical hints may be adopted with advantage:—

(*a*) The water end should always be brass lined and have a solid gun-metal plunger and a bucket rod of phosphor bronze. If cast-iron plungers are employed the rings should be of gun-metal if the pump is used with hot water, and of ebonite if used with cold feed.

(*b*) The valves and seatings are, of course, always brass or brass with specially hard facings, to reduce attrition and wear. They must be easily accessible and the seat rings readily rénewable.

(*c*) The piston speed at full duty should not exceed 30 feet per minute.

(*d*) In compound-tandem pumps, the H.P. cylinder should always be separated from the L.P. cylinder, so as to permit access to the glands for packing and examination.

(*e*) A separate multiple sight-feed lubricator should be fixed instead of grease cups, and thus ensure a uniform oil supply without the extravagance and wasteful flushing where cups are used.

(*f*) The pump duty when supplied at a specified steam pressure should never be less than 110 lbs. of water delivered against the boiler pressure for each lb. of steam applied to the pump.

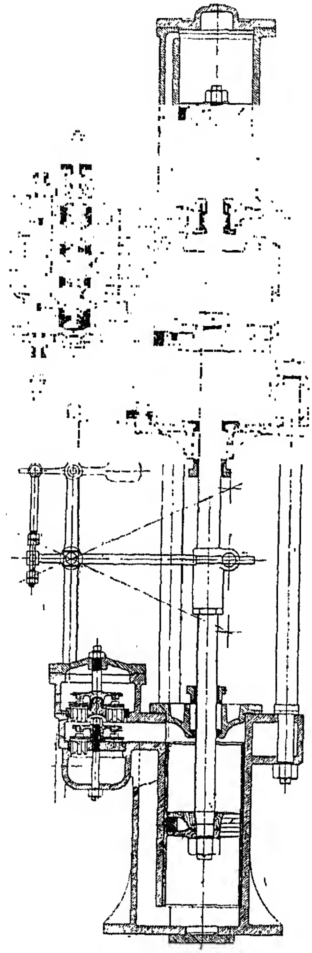


FIG. 38.

(*g*) The stroke should be adjustable while the pump is working, and the pump should start instantly at any point of its stroke.

Air vessels are provided on the suction as well as the delivery, and snifting cocks should always be fitted for the admission and control of air. Steam feed pumps should be supplied with a drip tray on which each should stand to preserve cleanliness, and with relief valves in each cylinder and on the pump deliveries. An automatic stroke counter should be fitted to the valve gear.

The following Table, No. XXXIV., gives the particulars of various standard sizes of steam feed pumps, and is supplied by the courtesy of Messrs. J. P. Hall & Sons, Peterborough, England. An illustration of a typical pump is given in Fig. 38.

The approximate cost of tandem compound steam feed pumps before the war could be taken at from £23 to £17 per 1000 gallons capacity per hour for sizes ranging from 3000 to 12,000 gallons per hour; for single cylinder direct acting pumps the approximate costs were from £20 to £12 over the same range.

TABLE XXXIV.

STANDARD SIZES OF COMPOUND STEAM FEED PUMPS.

Diameter (inches).			Length of stroke (inches).	No. of strokes per minute.	Duty: gallons per hour.	Diameter of pipes (inches).				Floor space.	Height.	Total weight.
H.P. cylinder.	L.P. cylinder.	Pump.				Steam.	Exhaust.	Suction.	Discharge.	ft. in. ft. in.	ft. in.	tons.
6¼	9½	6¼	12	14	2,200	1	1¼	3	2½	2 0 × 2 0	6 10	0·65
6¼	9½	6¼	15	14	2,600	1	1¼	3	2½	2 0 × 2 0	7 10	0·70
7½	12	7½	12	14	3,000	1	1½	3½	3	2 4 × 2 4	7 0	0·80
7½	12	7½	15	14	3,800	1	1½	3½	3	2 4 × 2 4	8 1	0·87
8	12	7½	18	13	4,200	1	1½	3½	3	2 6 × 2 6	8 10	1·00
9	13¾	8½	18	12	5,000	1¼	1¾	4	3½	2 8 × 2 8	8 4	1·40
9	13¾	8½	21	12	6,000	1¼	1¾	4	3½	2 8 × 2 8	9 1	1·55
9¾	15¼	9¾	18	12	7,000	1¼	2	4½	4	3 0 × 3 0	8 6	1·60
9¾	15¼	9¾	21	12	8,000	1¼	2	4½	4	3 0 × 3 0	9 3	1·75
11	18	10½	24	12	10,000	1½	2¼	6	6	3 4 × 3 4	10 4	2·55
12¼	20	11¾	24	12	12,000	1¾	2¼	6	6	3 6 × 3 6	10 4	2·95

The following tests taken with Hall's compound boiler feed pumps will be useful for reference, and confirm the specification given on a previous page:—

TABLE XXXV.

TESTS WITH STEAM FEED PUMPS.

A. TEST OF PUMP, 11″ × 18″ × 10½″ × 24″ STROKE, WITH SATURATED STEAM.

Boiler pressure.	Pressure on pump.	Duration of test.	Total No. of double strokes.	Weight of steam used.	Weight of water delivered.	Water delivered per lb. of steam used.
lbs.	lbs.	mins.		lbs.	lbs.	lbs.
200	225	10	145	168	19,700	117
200	200	10	130	140	17,600	125
B. TEST OF PUMP, 9″ × 13¾″ × 8½″ × 18″ STROKE, WITH SATURATED STEAM.						
160	165	10	174	99	11,842	119·6
160	170	10	144	81	9,801	120

Electrical pumps are either of the three-throw or rotary patterns. Fig. 39 shows a typical Edwards' single-acting pump. This type of pump, while costing more initially, is very efficient in working; a duty of 1000 gallons of water per hour can be given with an input of 240 watts.

Table No. XXXVI. sets out the particulars of standard sizes of electrically driven three-throw pumps (see p. 131).

Rotary Feed Pumps.—Rotary feed pumps, driven either by a steam turbine or by a motor, are now very generally used. If motor driven, the motor should be able to start against a load of 1¼ times the full load running torque.

A typical pump runs at a speed of 5000 to 6000 R.P.M., and absorbs 160 H.P., when delivering 35,000 gallons per hour against a steam pressure of 225 lbs. The exhaust from the turbine is discharged through a nozzle into the feed tank and the heat units are thus used to raise the temperature of the feed water before the latter enters the economiser. A motor pump running at 1500 R.P.M. and absorbing 80 H.P. will deliver 20,000 gallons per hour against a steam pressure of 250 lbs. per square inch.

A multi-stage rotary pump is generally fitted with impellers of special gun-metal mounted on a nickel steel shaft and revolving within a cast-iron casing. Each stage of the pump is self-contained with renewable neck rings and bushes, and the guide

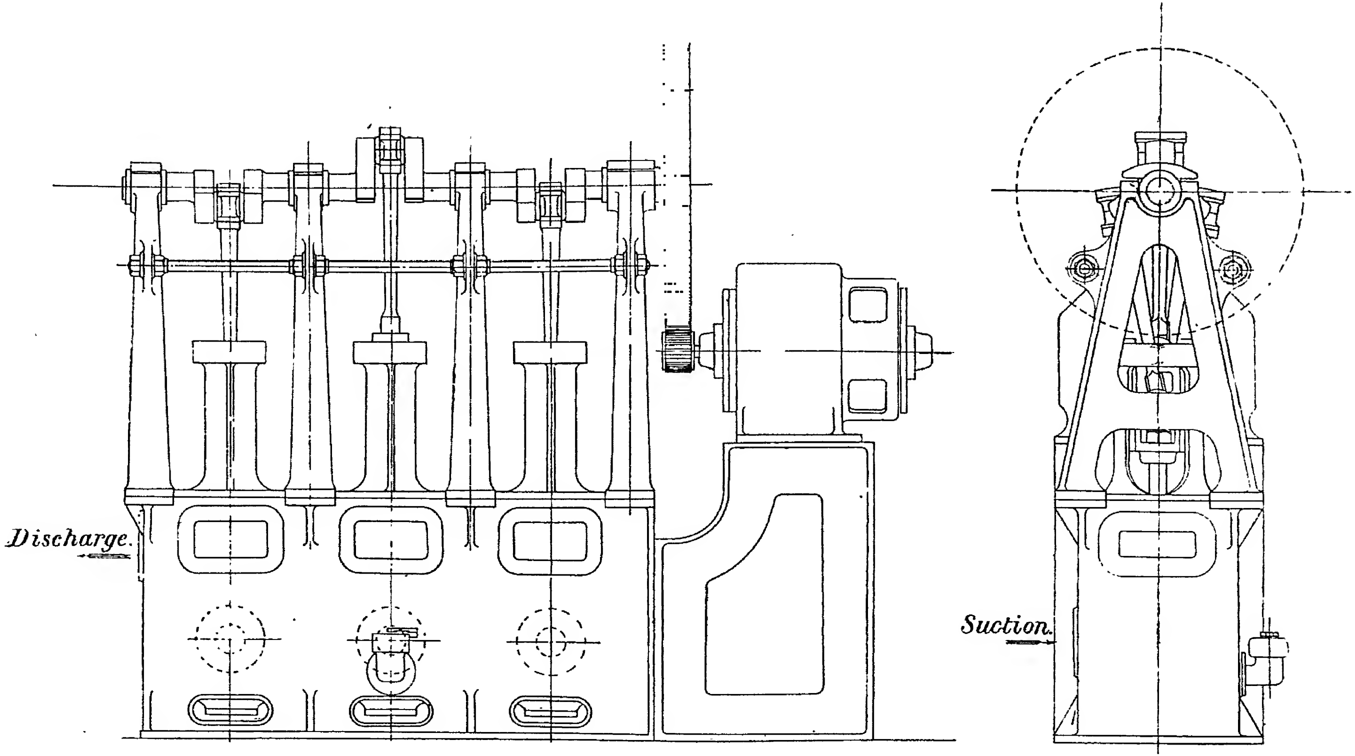


FIG. 39.

TABLE XXXVI.

ELECTRICALLY-DRIVEN TRIPLEX BOILER FEED PUMPS.

Suitable for a boiler pressure of 180 lbs. per square inch, and plunger speed at full load not exceeding 70 feet per minute. Each pump provided with a double reduction machine-cut gear, cast-iron base for motor, raw hide pinion, delivery air vessel, bye-pass and relief valve on delivery pipe.

Duty in gallons per hour.	Sizes and particulars of pumps.								Motors.	
	Diameter of plungers.	Stroke.	Revs. per min.	Diam. suction pipe.	Diam. delivery pipe.	Including above accessories, packing for shipment, and delivery F.O.B. London.				
						Weight.	Pre-war price iron fitted.	Extra for gun-metal fitting.	Min. B.H.P.	Approx. R.P.M.
	ins.	ins.		ins.	ins.	lbs.	£	£		
1,000	3	6	39	3	2½	2,700	65	6	3·2	800
2,000	4	6	43	3	2½	3,400	76	7	6·4	800
3,000	4½	8	39	3	2½	3,900	93	9·5	9·6	800
4,000	5	8	42	4	3	5,400	121	10·75	12·2	800
5,000	5½	8	43	4	3	8,100	157	11·75	15·2	800
6,000	6	8	43½	5	4	8,600	167	12·75	18·2	700
7,000	6½	8	43	5	4	8,900	172	14·5	21·2	700
8,000	6½	10	39	5	4	10,200	215	16	24·2	700
9,000	7	10	38	5	5	10,600	222	19·25	27·2	600
10,000	7½	10	37	6	5	13,400	270	22·25	30·4	600

SIZE OF ELECTRICAL TRIPLEX PUMPS.

Duty in gallons per hour.	Length. ft. ins.	Width. ft. ins.	Height. ft. ins.
1,000	5 0	4 3	3 3
2,000	5 0	4 9	3 9
3,000	6 3	5 7	4 3
4,000	6 3	5 7	4 3
5,000	6 6	5 7	4 6
6,000	6 6	5 9	4 6
7,000	6 9	5 9	4 9
8,000	8 9	7 5	6 3
9,000	8 9	7 5	6 3
10,000	9 0	7 5	6 6

vanes are of gun-metal with renewable tips. The shaft glands are lined with white metal and are provided with water packing

and bushes of gun-metal. The bearings are lined with anti-friction metal and are lubricated by oil rings.

The whole of the revolving parts of the pump must be in hydraulic balance so that there is neither end nor side pressure on the shaft. A snifting cock should be fixed to the top of the pump casing to emit air.

These pumps are frequently installed with a system of automatic feed control and lend themselves to a simple and easy regulation of the supply of feed water dependent on the height of water in the gauge glass and the rate of evaporation.

Hot Wells should be of liberal capacity and so arranged in level with respect to the feed pumps that the water may flow to the pump barrels, and not have to be lifted. In fact, the condensed-steam discharge should be raised by small auxiliary pumps to a sufficiently high level so that the water will gravitate through any necessary oil-extracting plant to the hot well, thence through the feed-water meters to the pumps. A systematic lay-out on this principle is desirable. Hot wells should be arranged to have approximately $\frac{1}{20}$ the capacity of the normal evaporation of the boiler-range with which they are connected. It is desirable to subdivide a hot well into two compartments so as to enable valves to be examined and the tanks to be cleaned and painted. A supplementary "make-up" supply must be provided through ball floats and valves. All discharge pipes leading from the condensers should be submerged, so as to prevent the water falling through the air and thus becoming aërated. Aëration of feed water is a frequent cause of corrosion in boilers.

Meters. — There are several types of feed-water meters. These must be inserted on the suction side whenever possible.

The Kennedy hot-water meter is frequently used to measure boiler feed. This meter is very simple and depends on the action of a piston, the length of travel of which in its cylinder and the number of strokes are the measure of the water flowing through the meter. The actuating mechanism is of the simplest description, being merely a cock-key which is always in one of two positions, leading the inlet water alternately to the bottom and top of the piston. The piston rod passing through a gland

terminates in a rack, the pinion gearing into which actuates the index mechanism through bevel wheels. A great accuracy can be obtained with these meters, since the measure of the water passing is dependent not alone on the strokes made by the piston, but also on the length of travel. The following Table, No. XXXVII., gives the standard sizes up to 24,000 gallons per hour :—

TABLE XXXVII.

KENNEDY HOT WATER METER : STANDARD SIZES.

Bore of inlet and outlet (inches).	Normal delivery (gallons per hour).	Maximum delivery (gallons per hour).	Weight of meter (lbs.).
$\frac{1}{2}$	400	850	168
$\frac{3}{4}$	600	1,500	224
1	1,000	2,000	294
$1\frac{1}{2}$	1,700	3,000	476
2	3,600	5,000	812
3	5,000	8,000	1176
4	10,000	15,000	2016
6	16,000	25,000	2968
8	24,000	35,000	5040

The "Venturi" meter is now frequently used in power house work, both for feed water and for circulating water systems. This meter is dependent on the law that water flowing through a pipe of diminishing area loses the pressure it exerts laterally as it gains in velocity. A "Venturi" tube inserted in any pipe consists of two truncated cones and a "throat," and within a known limit of statical pressure, a sufficiently high velocity of the water will cause it not only to lose all lateral pressure, but also to form a vacuum. Small pipes are led away from a point at the full bore of the main and also from the throat, and these can be led to a distance as great as 1000 feet from the "Venturi" tube without impairing the accuracy of the record. The pipes are led to a recorder which may be placed, if required, in the Resident Engineer's office, and is generally fitted with a recording drum, and also with a counter giving the total quantity passed. The registration can also be done by an electrical method if desired. The recorder

consists of a mercurial U-tube connected to the full bore pipe and to the throat and thus registering the "Venturi" head between the two points; and also of clockwork and gear which are controlled by the U-tube. The connection between these two factors, pressure and time, is made by means of floats resting on the mercury in the U-tube. The "Venturi" meter is entirely independent of the temperature of the water passing. The only thing necessary in practice is to see that the throat is free from scale or deposit, which can readily be done by examination from a hand hole provided for the purpose. Where used in conjunction with boiler-feed pumps, it is advisable to use an auxiliary tank to equalize the head and serve as an accumulator as shown in Plate VII., which depicts the installation of these meters for the Bahia Blanca power house. The average price for boiler feed water meters before the war was £25 per 1000 gallons per hour.

Blow-down Pipes and Sumps.—Suitable steel necks are riveted to the front plates of drum-type boilers, to carry the blow-down valve. In water-tube boilers the mud drum is usually separated from the boiler proper and a blow-down pipe is connected to the drum and led to the outside of the brick casing with the blow-down valve attached at that point. In some cases the mud drum is prolonged through the side wall. The valve should always have a cast steel body with brass parts and preferably be a parallel slide valve, a type which minimizes the risk of scoring through water and grit blowing through when it is supposed to be closed, with consequent loss of water and of heat units. This type of valve also enables the washing out of the boiler containing bits of scale, etc., to be done with a minimum risk of damaging the valve. With corrosive waters or those containing much scale-forming material, it is good practice to have a cock and valve arranged in series, the fitting nearest the boiler being always opened last and closed first. Thus the fitting farthest from the boiler never has to be shut or opened under pressure, and the valve and seat are always kept in good condition. The blow-down pipe must be laid in a trench so as to be accessible. It should be arranged with easy bends to prevent lodgment of scale and sludge, and

with plenty of standard expansion bends in a long length of pipe work. The end is taken down to a suitable sump outside the power house, and is usually carried slightly below the overflow level of the sump. The latter must be of liberal dimensions, especially in cases where it discharges into public sewers, so as to allow the water to cool before it is finally discharged. In such cases it is better to arrange a two-compartment sump, the blown-down pipe discharging into one compartment and the latest discharge from the hot sump displacing the standing water in the other compartment which overflows to the sewer. The sump should be covered with checker plating and fitted with an exhaust pipe carried to the eaves of the building to discharge vapour. The blow-down pipe is usually 4 inches in diameter, and the exhaust pipe is preferably 6 inches in diameter, but not less than 4 inches.

CHAPTER V

STEAM AND FEED-PIPE SYSTEMS

THE principles to be aimed at both in the steam-pipe and the feed-pipe systems of any power house are (*a*) simplicity and (*b*) reliability. As the boilers are dependent upon the reliability of the water supply, so the engines or turbines are dependent on the reliability of the steam supply; each is a link in the chain between the fuel at the one end and the electrical output at the other. As has before been stated, the ideal of simplicity would be one boiler, one steam pipe, and one engine; each set a complete unit in itself and independent of its neighbours. As, however, it is not practicable either to build so large a boiler in one unit to supply the larger engines or turbines, or so to arrange matters that Boiler A can always supply Engine A, some departure from this ideal of simplicity is necessary. Firstly, in the larger power houses several boilers are necessary for the supply of each turbine; secondly, cleaning, repairs to brickwork, replacement of fire bars, etc., require the periodical laying off of each boiler so that it comes about in practice that boilers A, C, D, and F, it may be, are required to supply turbines A and B while boilers B and E are laid off for some reason or other. Therefore a connecting pipe or header is usual for the paralleling of the steam supply, and this is provided for in different ways according to the lay-out of the plant. Various examples of typical steam-pipe systems will now be discussed. The designer must bear in mind the following necessary or axiomatic rules.

Principles to be Observed in Pipe Designs.—(*a*) The system to be as simple and direct as possible.

(*b*) The pipes to be laid consistently to agreed and recognized points of drainage, e.g. the turbine separators.

(*c*) As few points of drainage to be incurred as are consistent with safety.

(*d*) All horizontal valves to be "full way," so as to prevent accumulation of water.

(*e*) All expansion bends to be laid in a horizontal plane, so as to avoid pockets for water.

(*f*) Elasticity to be given to the system by a sufficient number of bends (but not too many).

(*g*) A single branch from each boiler to be taken into a single header common to the boilers and turbines comprising the completed unit or part of the power house.

(*h*) This header to be subdivided by valves, where necessary, for the proper protection of the system.

(*i*) A single branch pipe to lead from the header to the engine or turbine; or with very large turbines, two pipes may be arranged as shown in Figs. 14 and 44 so as to avoid very large diameters.

(*j*) The main header preferably to be arranged on the boiler-house side of the engine-room wall so as to be clear of crane slings, etc. Sometimes this is not possible, and the header has to be arranged within the engine-room when it may be placed above or beneath a platform to give accessibility to valves.

(*k*) All valves to be operated both from the pipe-work platform connecting with the boiler tops, etc., and also from the ground level through extended spindles.

(*l*) All valves to be marked clearly "open" or "shut" in the language of the country in which the power house is situated, and arrowheads cast on the hand wheels to show the direction of rotation. In subsequent working, labels marked "Shut" should always be attached to the valve hand-wheels when work is being carried on in any section beyond this valve and controlled by it.

(*m*) All the pipes, flanges, bends, and tees to be of the standard dimensions, preferably of those of the recognized British Engineering Standards Association.

(*n*) The pipes to be large enough to minimize the fall of pressure between boilers and engine stop valves.

(*o*) At the same time the pipes should be as small as possible so as to reduce radiation losses—quite a factor to be considered in a big system.

(*p*) The lengths to be as great as are practicable, so as to reduce the number of joints to a minimum.

(*q*) The joints should be made with corrugated metal rings, and a suitable good paint, which should neither soften under water nor contract with heat, and should be as thin as possible. The rings should be of such diameter as to lie both within and without the bolt circle. Brass rings are used for saturated steam, and metal rings with superheated steam.

(*r*) The sectionalizing should be such that the failure of any one pipe should affect only one turbine or one boiler unit.

Specification of Materials.—Steam pipes of smaller sizes up to 12 inches diameter are now always specified to be solid drawn weldless pipes made from the best quality acid open hearth steel, having a tensile strength of from 21·6 to 29·6 tons per square inch with an elongation of 27 per cent. in a test length of 2 inches.

Pipes of larger diameter, say, from 13 inches to 16 inches diameter, are made lap-welded, the steel having a tensile strength of 22 to 26 tons per square inch with an elongation of 25 per cent. in 8 inches. Steam pipes can now be made up to 30-foot lengths according to the position of the riveted branches or valves, and this greater length reduces the number of joints. The difficulties of carriage and of erecting such lengths, however, often prevent their adoption. The branches on all pipes above 6 inches diameter are riveted on so as to reduce the number of joints in the system and to avoid the use of cast tee pieces. These branches have saddles which are accurately shaped to fit the curvature of the main length, drilled in position, and then riveted up. The flanges of pipes up to and including 6-inch pipes are screwed on to the pipe, and the pipe ends are expanded and beaded into a recess on the flange faces. In the case of pipes over 6 inches diameter riveted flanges are used. They are accurately bored and shrunk on to the pipes, and after being riveted and caulked and the ends of the pipes hammered up to the flanges, the latter are accurately faced, turned on the edges, and

machined or knifed out at the backs to give a level bearing surface for the boltheads and nuts.

Tables Nos. XXXVIII. and XXXIX. give the British Engineering Standards Association sizes of pipes, flanges, bends, and tees. (Extract from British Standard Specification, No. 10 1904.)

TABLE XXXVIII.

THIN WELDLESS STEEL STEAM PIPES (FOR STRAIGHTS).

(Steam pressure 225 lbs. per square inch.)

Internal diameter of pipe.	Flanges.				
	Diameter.	Thickness.	Diameter of bolt circle.	Diameter of bolts.	No. of bolts.
ins.	ins.	ins.	ins.	ins.	
3	8	1	6½	⅝	8
3½	8½	1	7	⅝	8
4	9	1⅛	7½	⅝	8
5	11	1¼	9¼	¾	8
6	12	1¼	10¼	¾	12
7	13¼	1⅜	11½	¾	12
8	14½	1⅜	12¾	¾	12
9	16	1½	14	⅞	12
10	17	1½	15	⅞	12
12	19¼	1⅝	17¼	⅞	16

TABLE XXXIX.

TEES AND BENDS.

(Steam pressure 225 lbs. per square inch.)

Internal diameter of pipe.	Centre to flange face.	Radius of centre-line of bend.
ins.	ins.	ins.
3	6	4
3½	6½	4½
4	7	4¾
5	8	5½
6	9	6½
7	10	7¼
8	11	8¼
9	12	9
10	13	10
12	15	11¾

All bolts and nuts (studs should not be allowed) are specified to be of soft and ductile steel, and to stand bending double, both hot and cold, without showing defects. The steel should give a tensile strength of from 26 to 30 tons per square inch, with an elongation of 25 per cent. in a test length equal to eight times the diameter of the bar. All heads, stems, threads, and nuts should be of accepted Whitworth or British Engineering standard, and all nuts should be a spanner-tight fit on their bolts. In erecting pipe work, the lengths of bolts should be so selected for particular flanges that when set up in position the shank should just show through the nut.

Inspection and Testing.—All pipes should be inspected during construction, cleaned both inside and out, and assembled and coupled together at the makers' works. This is usually done in practicable lengths so as to facilitate the inspector's examination and hydraulic testing. The tubes from which pipes up to and including 6 inches diameter are manufactured are usually tested to 1000 lbs. per square inch, and above 6 inches diameter to 600 lbs. per square inch. When the pipes have had their flanges attached and faced up, they are usually tested again by hydraulic pressure up to 350 lbs. per square inch.

In erecting pipes no springing into position should be allowed, and if well made and erected the pipes should assemble accurately. Expansion bends may be excepted; these should be so offered up that the "spring" in them when cold should equal the spring in the other direction when hot. These, therefore, must be slightly sprung into position during erection. The interiors of all pipes should be most carefully cleaned out after erection, so as to remove excess jointing cement, etc., which may collect during erection.

Steam Velocities in Pipes.—Any increase in the diameter of a pipe obviously increases its cross-sectional area at a greater rate than its circumference, since the circumference is a function of the diameter, whereas the area is a function of the square of the diameter. Thus, it is easy to choose a pipe of such size as to pass a given quantity of steam without undue fall of pressure, and, at the same time, to have the outside area of pipe small enough to keep the radiation losses as small as possible. The

external surface of steam pipes is usually from 0·225 square foot to 0·24 square foot per K.W. rated output of the plant. It is usual to base steam-pipe dimensions on steam velocities of the following values, viz.:—

Saturated steam.	Pipes up to and including 3 inches diameter	75 feet per sec.
,,	Pipes above 3 inches diameter . . .	90 ,, ,,
Superheated steam.	Pipes up to and including 9 inches diameter	120 ,, ,,
,,	Pipes above 9 inches diameter . . .	140 ,, ,,

The fall of pressure in a well-designed pipe system between boilers and turbine should not exceed $1\frac{1}{2}$ per cent. of the initial pressure.

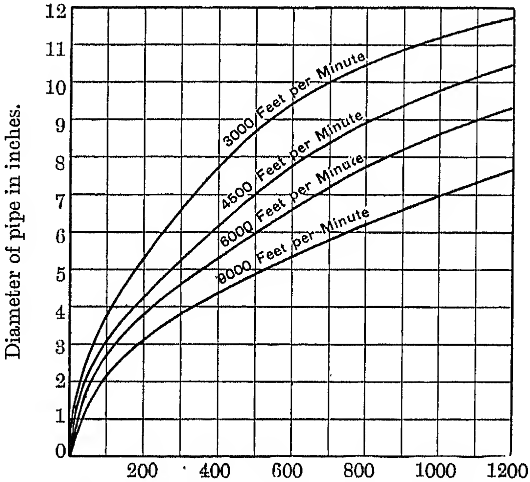


FIG. 40.—Weight of steam in lbs. per minute.

Flow of Steam through Pipes.—Fig. 40 shows curves giving the relation between the weight of steam passed per minute through pipes of different diameters at velocities between 3000 and 9000 feet per minute, and based on 180 lbs. gauge pressure per square inch. Since the density of a given volume of steam varies directly as the pressure, according to Boyle's law, any other curves for other initial pressures than the datum used for the above curves can be easily drawn.

Tables Nos. XL., XLI., and XLII. give the velocities in pipes for saturated and superheated steam at 120, 160, and 200 lbs. pressure respectively. In modern turbine practice a speed of 5400 feet per minute is usually adopted.

TABLE XL.

Flow of Steam through Pipes.

Steam velocities.		Diameter of pipe.	Steam quantities in lbs. per hour. Working pressure, 120 lbs. per sq. in. = 8·5 kg. per sq. cm. = 8 atmospheres. Saturated steam.	Steam superheated by 100° F., 55° C.	150° F., 83° C.	200° F., 110° C.	250° F., 140° C.	300° F., 167° C.
Speed of steam.	Sat. 75 ft., superh. 100 ft. per sec.	ins. $\frac{1}{2}$	110	130	120	110	110	100
		$\frac{3}{4}$	250	290	270	260	245	230
		1	440	510	480	460	435	410
		$1\frac{1}{4}$	690	800	750	710	680	640
		$1\frac{1}{2}$	1,000	1,150	1,080	1,020	980	930
		2	1,770	2,050	1,920	1,820	1,740	1,650
		$2\frac{1}{2}$	2,770	3,200	3,000	2,840	2,700	2,570
		3	4,000	4,600	4,300	4,100	3,900	3,700
Speed of saturated steam, 90 ft. per sec.	Speed of superh. steam, 120 ft. per sec.	$3\frac{1}{2}$	6,500	7,500	7,100	6,700	6,400	6,000
		4	8,500	9,800	9,200	8,700	8,400	7,900
		$4\frac{1}{2}$	10,800	12,500	11,700	11,000	10,600	10,000
		5	13,300	15,400	14,400	13,600	13,000	12,300
		6	19,000	22,000	20,800	19,600	18,800	17,700
		7	26,000	30,100	28,000	26,700	25,600	24,000
		8	34,000	39,400	37,000	35,000	33,400	31,500
		9	43,000	50,000	47,000	44,000	42,000	40,000
	Speed of superh. steam, 140 ft. per sec.	10	53,000	72,000	67,000	64,000	61,000	57,500
		11	64,000	87,000	81,000	77,000	74,000	70,000
		12	77,000	104,000	97,000	92,000	87,000	83,000
		13	90,000	122,000	114,000	108,000	103,000	97,000
		14	104,000	141,000	132,000	125,000	119,000	113,000
		15	120,000	162,000	150,000	143,000	137,000	130,000
		16	136,000	184,000	172,000	163,000	156,000	147,000
		17	154,000	208,000	194,000	184,000	176,000	166,000
		18	172,000	233,000	218,000	206,000	197,000	186,000
		19	192,000	260,000	243,000	230,000	220,000	208,000
		20	212,000	290,000	270,000	254,000	243,000	230,000

Table No. XLIII. (p. 145), prepared by Messrs. Babcock & Wilcox, gives the flow of steam through pipes of various sizes and at various pressures. The weight of steam delivered is calculated on a fall of one pound pressure through straight pipes each having a length equal to 240 times its own diameter.

TABLE XLI.

Flow of Steam through Pipes.

Steam velocities.		Diameter of pipe.	Steam quantities in lbs. per hour. Working pressure, 160 lbs. per sq. in. = $11\frac{1}{4}$ kg. per sq. cm. = 11 atmospheres.					
			Saturated steam.	Steam superheated by				
				100° F., 55° C.	150° F., 83° C.	200° F., 110° C.	250° F., 140° C.	300° F., 167° C.
		ins.						
Speed of steam.	Sat. 75 ft., superh. 100 ft. per sec.	½	140	160	150	145	140	130
		¾	320	370	350	330	310	290
		1	570	660	610	580	550	520
		1¼	885	1,030	960	900	870	820
		1½	1,280	1,480	1,380	1,300	1,250	1,180
		2	2,260	2,630	2,450	2,300	2,200	2,100
		2½	3,540	4,100	3,850	3,600	3,500	3,300
		3	5,100	5,900	5,500	5,200	5,000	4,700
Speed of saturated steam, 90 ft. per sec.	Speed of superh. steam, 120 ft. per sec.	3½	8,300	9,650	9,000	8,500	8,200	7,700
		4	10,900	12,600	11,800	11,000	10,700	10,000
		4½	13,800	16,000	15,000	14,000	13,500	12,700
		5	17,000	19,700	18,400	17,400	16,700	15,700
		6	24,500	28,300	26,500	25,000	24,000	22,600
		7	33,300	38,600	36,000	34,000	32,600	31,000
		8	43,500	50,000	47,000	44,500	43,000	40,000
		9	55,000	64,000	60,000	56,000	54,000	51,000
	Speed of superh. steam, 140 ft. per sec.	10	68,000	92,000	86,000	81,000	78,000	73,000
		11	82,000	110,000	104,000	99,000	94,000	89,000
		12	98,000	132,000	124,000	117,000	112,000	105,000
		13	115,000	155,000	145,000	137,000	130,000	124,000
		14	133,000	180,000	168,000	160,000	152,000	144,000
		15	153,000	207,000	193,000	183,000	175,000	165,000
		16	174,000	236,000	220,000	210,000	200,000	186,000
		17	196,000	266,000	250,000	235,000	224,000	210,000
		18	220,000	300,000	280,000	264,000	250,000	237,000
		19	246,000	330,000	310,000	291,000	280,000	264,000
		20	272,000	370,000	344,000	325,000	310,000	293,000

For any other *loss of pressure* multiply by the square root of the given loss. For any other *length of pipe* divide 240 by the given length expressed in diameters, and multiply the figures in the table by the square root of this quotient, the result giving the flow of steam for one pound loss of pressure. Conversely,

dividing the given length by 240 will indicate the loss of pressure for the flows specified in Table No. XLIII. When calculating the flow through steam pipes a differentiation in favour of the turbine must be made as compared with the intermittent supply to reciprocating engines. This may represent 8 per cent. in favour of the turbine.

TABLE XLII.

FLOW OF STEAM THROUGH PIPES.

Steam velocities.		Diameter of pipe.	Steam quantities in lbs. per hour. Working pressure, 200 lbs. per sq. in. = 14 kg. per sq. cm. = 13·6 atmospheres.					
			Saturated steam.	Steam superheated by 100° F., 55° C.	150° F., 83° C.	200° F., 110° C.	250° F., 140° C.	300° F., 167° C.
Speed of steam.	Sat. 75 ft., superh., 100 ft. per sec.	ins. ½	170	200	190	180	170	160
		¾	390	450	420	400	380	360
		1	690	800	750	700	675	640
		1¼	1,080	1,250	1,170	1,100	1,050	1,000
		1½	1,550	1,800	1,680	1,600	1,520	1,430
		2	2,750	3,200	3,000	2,800	2,700	2,550
		2½	4,300	5,000	4,700	4,400	4,200	4,000
		3	6,200	7,200	6,700	6,400	6,100	5,700
Speed of saturated steam, 90 feet per sec.	Speed of superh. steam, 120 ft. per sec.	3½	10,000	11,700	11,000	10,500	10,000	9,400
		4	13,200	15,300	14,300	13,700	13,000	12,200
		4½	16,700	19,400	18,000	17,400	16,400	15,500
		5	20,600	24,000	22,400	21,400	20,000	19,000
		6	29,600	34,400	32,000	31,000	29,000	27,500
		7	40,000	47,000	44,000	42,000	40,000	37,400
		8	53,000	61,000	57,000	55,000	52,000	49,000
		9	67,000	78,000	72,000	70,000	66,000	62,000
	Speed of superh. steam, 140 ft. per sec.	10	82,000	112,000	104,000	99,000	94,000	90,000
		11	100,000	135,000	126,000	120,000	114,000	108,000
		12	119,000	160,000	150,000	142,000	136,000	128,000
		13	140,000	190,000	176,000	167,000	160,000	150,000
		14	160,000	220,000	205,000	194,000	185,000	175,000
		15	185,000	250,000	235,000	222,000	210,000	200,000
		16	210,000	286,000	267,000	253,000	240,000	230,000
		17	240,000	320,000	300,000	286,000	273,000	260,000
		18	267,000	360,000	340,000	320,000	306,000	290,000
		19	300,000	400,000	380,000	360,000	340,000	320,000
		20	330,000	450,000	420,000	395,000	380,000	360,000

TABLE XLIII.

FLOW OF STEAM THROUGH PIPES.

Initial gauge pressure lbs. per sq. in.	Diameter of pipe in inches. Length = 240 diameters.													
	3/4	1	1½	2	2½	3	4	5	6	8	10	12	15	18
	Weight of steam per minute in lbs. with 1 lb. loss of pressure.													
100	2·95	5·25	14·5	25·96	39·07	64·18	118·47	195·6	293·1	534·6	862·6	1270·1	2032	2975
120	3·16	5·63	15·5	27·85	41·93	68·87	127·12	209·9	314·5	573·7	925·6	1363·3	2181	3193
150	3·45	6·14	17·0	30·37	45·72	75·09	138·61	228·8	343·0	625·5	1009·2	1486·5	2378	3481
180	3·67	9·28	18·29	33·54	50·70	77·00	147·90	241·8	361·2	674·5	1088·2	1602·9	2564	3754
200	3·83	9·726	18·96	34·40	53·00	80·64	154·00	253·1	377·5	707·0	1139·7	1679·0	2686	3931

Tests for Moisture in Steam.—Tests for moisture in steam can be made by a special form of Barrus wire-drawing calorimeter, the principle of which depends on the fact that dry steam when expanded from a higher to a lower pressure without doing external work becomes superheated, the amount of superheat being dependent on the difference of pressure. If the steam is wet then the moisture must first be evaporated, and thus the superheating will be proportionately less.

The percentage wetness can be deduced with fair accuracy from the following formula :—

$$X = \frac{H - 1146{\cdot}6 - 0{\cdot}48\,(T - 212)}{L} \times 100$$

where H = total heat above 32° Fahr. in the steam at boiler pressure,

L = latent heat of the same,

T = temperature (° Fahr.) shown by the lower thermometer in the calorimeter.

When using such an instrument very great care must be taken to calibrate it, about which there are, however, some difficulties. Reference can be made to works on Thermodynamics for further information.

Arrangements of Steam Piping.—Fig. 41 shows the arrangement of steam piping adopted by the Author for Bahia Blanca, Argentina.

Here it will be seen that the boilers and engines are back-to-back, thus enabling a simple system to be used. Tracing from boiler to engine, from the boiler-stop valve the 7-inch pipe rises to the highest point in the system and thence falls continually to the lowest point, i.e. the engine separator. There is a continuous header 10 inches in diameter connecting the several branch pipes, with suitable section valves as shown in the figure. In this case, in addition to the drains from the separators, there are, as shown, pockets riveted up to the header at certain points in order to drain the main header when cut up into sections.

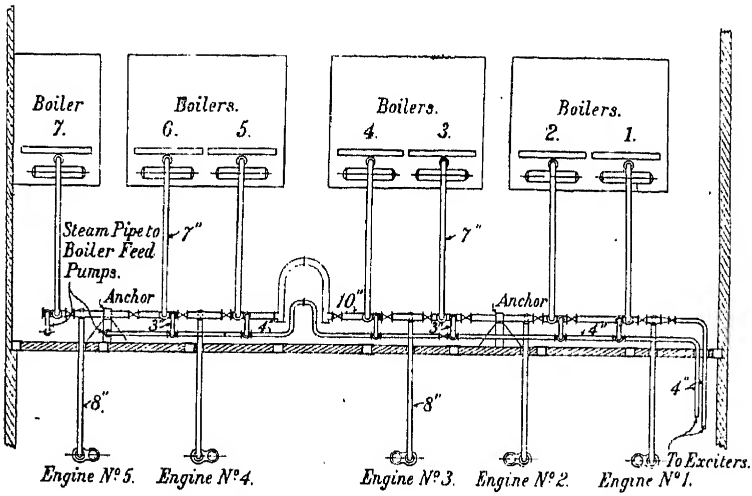


FIG. 41.

To each of these a steam trap is fixed. The section valves are worked both from an upper platform giving access to the boiler tops and also from the ground level. The header is situated in the boiler house, thus giving a better appearance to the engine room, and also lessening the chances of escaping steam from a bad joint in the engine-room. The header is anchored at two points only as shown; these and the boiler stop and engine separator flanges are the only fixed points, and the pipe work is otherwise free to take up its own position, whether steam be on or not. The header is carried on roller supports, and is provided with a large horizontal expansion bend midway between

the two anchor brackets. As will be seen on reference to the figure, there are several ample bends to give elasticity to and prevent undue stresses upon the system.

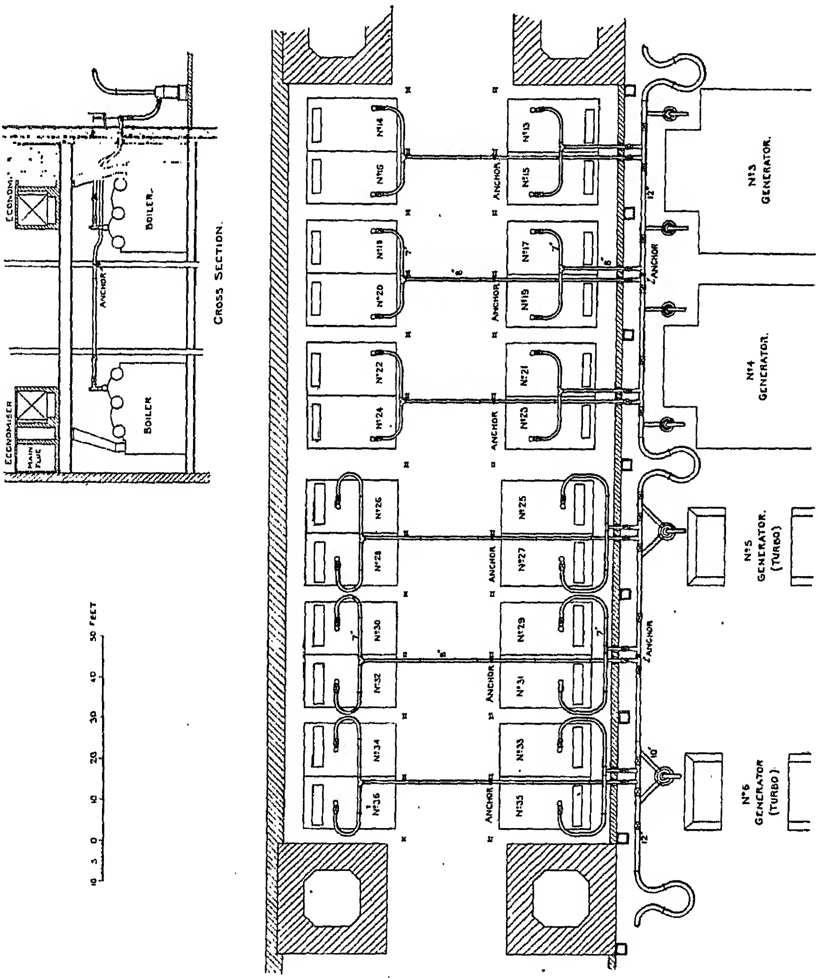


FIG. 42.

Fig. 42 shows the arrangement of pipe work at the Greenwich Power House of the London County Council. Here the supply is given from a double bank of boilers, each pair of boilers, moreover, being taken as a unit with one common branch pipe

(8 inches diameter) to the header. The header is situated in the engine-room in this example, and is anchored midway between each pair of expansion bends as shown in the figure. The long branch pipes from the back row of boilers are each anchored at a stanchion approximately midway. The arrangement of valves (particularly in that portion supplying the turbo-generators) will repay study by the designer since it embodies the safest practice with the greatest simplicity. As in the former example, the branch pipe from the boilers (in this case the back row of boilers) is the highest point and the pipes fall thence to the separators.

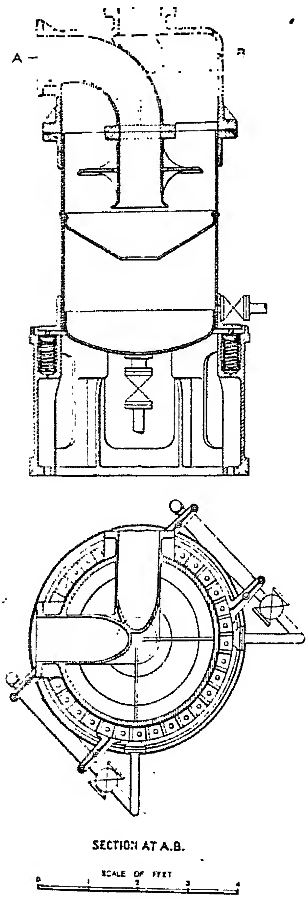


FIG. 43.

An interesting detail of this system is shown in Fig. 43, which illustrates a movable separator adopted by Mr. J. H. Rider in connection with the Greenwich sets. Each separator, which is the lowest part of the main steam range, is mounted upon special stools with ball bearings and springs, and is thus free to move in any direction, either up, down, or sideways. The water is drained off from the lowest part by duplicate steam traps and a hand-worked blow-down valve. These separators have proved most effective in practice by relieving the branch pipes from many strains. A separator of this kind may safely be recommended for large power plants.

The Engineering Advisory Board in connection with the London Power Bulk Supply Bills, of which the Author was a

member, were responsible for the designs of a projected very large power house in which an aggregate of 120,000 K.W. of turbo-generators was to have been installed. In this case the "bulkhead" principle was adopted, with eight boilers (four pairs) to each 12,000 K.W. turbo-generator, and the pipe design is shown in Fig. 44. Here the boilers are necessarily placed at right angles to the turbines on account of the large output of the latter. It will be seen that the steam from each pair of boilers (which had a rated evaporation of 45,000 lbs. per hour), was led

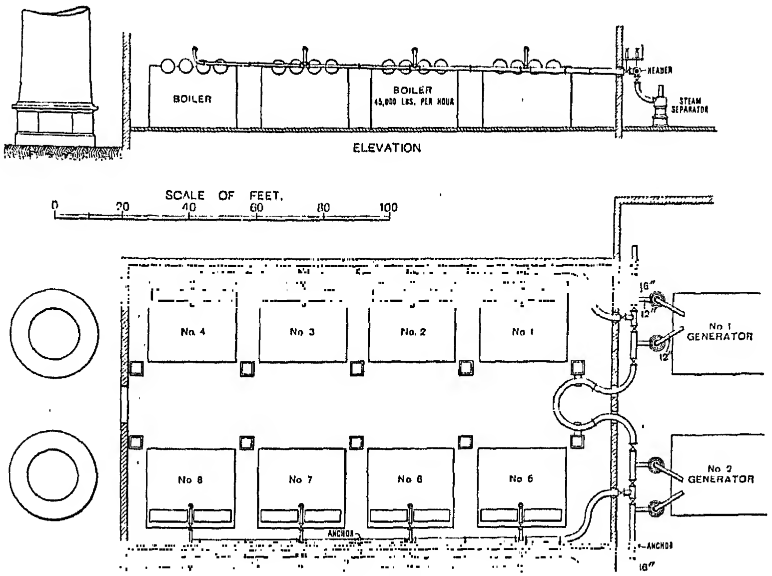


Fig. 44.

away by an 8-inch supply pipe leading up successively through a 12-inch, 14-inch, and ultimately a 16-inch pipe (as the supply from each successive boiler was picked up) to a 16-inch connecting header. Each turbine was to have been supplied from two 12-inch branch pipes as shown in the figure. Here, again, the system of drainage adopted was on the same principle as illustrated in Fig. 43.

The above descriptions of steam-pipe systems embody the principles laid down at the beginning of this chapter. On no account should ring mains be used in steam-pipe work. They

are things of the past, involving unnecessary expense, complications, and increased losses through radiation, and increased danger from water collection and water hammer, without giving any additional security to the supply.

Drainage of Steam Pipes.—As faulty drainage arrangements and improper provision for contraction and expansion have been the two primary causes of trouble in steam-pipe systems, it may be well to supplement the remarks already made.

Owing to the need for cutting up into sections at times, there is a tendency in any pipe system, however well designed, for water to accumulate in the "dead" sections through slight leaks past the section valves. Provision must therefore be made to get rid of this water without danger.

All draining arrangements should satisfy the three following conditions:—

(*a*) They must keep the pipe system entirely free from water when no steam is passing to the turbines; i.e. it should be possible to open the turbine stop-valve or bye-pass at any time without risk of carrying over water.

(*b*) Should any water form in the pipes while carrying steam to the turbines, or should any water come over from the boilers through priming, it must be prevented (1) from causing water hammer in the system, or (2) from reaching the turbines.

(*c*) Should any individual sections be laid off while neighbouring sections are alive, provision must be made to remove any possible accumulation of water in the dead section due to leakage, before the dead section is again opened out to the live steam.

To meet conditions A and B the pipes must be arranged so as to allow any water to flow by gravity (and with the steam) to certain defined points where it can be collected and drained off.

To meet condition C it is sometimes necessary to have supplementary drain pipes on the main header or boiler side of the boiler branch pipe. If possible, always avoid these; but when, owing to the relative positions of boilers and turbines, they are absolutely necessary, then let them be readily accessible. It must be recollected that these auxiliary drains are only for use when sections of the pipes have to be laid off between the two points of natural drainage formed by the turbine separators.

All high-pressure drains, through steam traps or direct blow-down, should discharge back to the hot well so as to prevent loss of heat and of good water.

Expansion of Steam Pipes.—The next point is to make due allowance for expansion and contraction. The coefficient of expansion of a steel pipe is 0·0000067 per degree Fahr., which represents an expansion of about 2·5 inches per 100-feet length of pipe in raising the temperature of the pipe from normal air temperature to 380° Fahr., i.e. the temperature of saturated steam at 180 lbs. gauge pressure. A further allowance of 0·8 inch per 100 feet must be made for every 100° Fahr. of superheat. Thus the allowance must be about $3\frac{1}{3}$ inches per 100 feet with superheated steam having a total temperature of 480° Fahr.

The strains set up by expansion are of course taken care of by suitable bends giving elasticity to the system. Moreover, the summation effect on a long length is reduced by anchoring the pipe at suitable intervals, the expansion on each section being taken up by the various bends. The movements set up by expansion or contraction are thus minimized and also controlled.

Standardization of Valves.—In laying out a pipe system, the number of valve sizes should be reduced to a minimum so as to standardize as far as possible and to reduce spare parts. All steam valves must be arranged with outside threaded spindles, and the full-way valve must always be used on horizontal lengths so as to give a clear and unobstructed bore through the system. Valves above 6 inches in diameter must always have bye-passes fitted. For vertical pipes the Ferranti type of valve is strongly to be recommended, the valve face and seating being so much smaller to maintain than in the case of the ordinary full-bore valve. Cast steel bodies and renewable valve seats are used in the best practice. Each valve should be tested at the makers' works, both under hydraulic pressure to at least twice the working pressure and by steam at a pressure of 200 lbs.

Lagging.—Special attention must be paid to the thorough insulation of steam piping, flanges, and valve bodies, and to the materials used. Every square foot of bare pipe passing superheated steam at a temperature of 337° Fahr. (100 lbs. by gauge)

will, with a surrounding atmospheric temperature of 62° Fahr., represent a loss of 625 B.Th.U.

There are various lagging materials in general use, and tests show that the percentage saving on bare pipes are as follows, with the materials specified :—

Hair felt	87 per cent.
Magnesia	87 ,, ,,
Asbestos	89 ,, ,,
Silicate cotton	90 ,, ,,

There are different methods of applying lagging, and much is to be gained by adopting a removable covering, especially for flanges and valves.

Magnesia sectional covering makes a very neat and thermally effective lagging, but has the objection that it will not stand much handling. For its cost, however, it is perhaps as effective a covering as can be obtained.

Hair felt is now never used with the higher temperatures owing to the danger of combustion.

The Author inclines to the use of removable asbestos coverings finished with planished sheet steel; this is more expensive than the magnesia sectional covers, but is more durable. Either of these types, however, provides a good lagging.

The lagging should be specified not to char, perish, or disintegrate when exposed continuously to a temperature of 420° C.; and the thickness should be such that the pipes when carrying superheated steam of a specified temperature should not lose more than 0·8 B.Th.U. per square foot of pipe surface (measured before the lagging is applied) per degree difference (Centigrade) between the steam and the surrounding atmosphere.

Properties of Saturated Steam.—Table No. XLIV. gives the properties of saturated steam.

Feed and Air-pump Discharge Pipes.—Feed piping at one time was invariably of copper. This is quite unnecessary, especially having regard to the modern treatment of feed water. Feed pipes are now invariably made from weldless mild steel with wrought steel flanges screwed on and expanded. Tee pieces are usually of high-grade cast iron.

TABLE XLIV.

Properties of Saturated Steam.

From Tables calculated by Lionel S. Marks and Harvey N. Davis, and published in 1909. Reproduced by permission of Messrs. Longmans, Green & Co.

Pressure in lbs. per sq. in. above vacuum.	Gauge pressure in lbs. per sq. in. (approx.)	Temperature in degrees F.	Total heat in heat units from water at 32° F.	Heat in liquid from 32° F. in heat units.	Heat of vaporization, or latent heat in heat units.	Density or weight of 1 cub. ft. in lbs.	Volume of 1 lb. in cubic feet.	Pressure in atmospheres above vacuum.
1	—	101·83	1104·4	69·8	1034·6	0·00300	333·0	·068
2	—	126·15	1115·0	94·0	1021·0	0·00576	173·5	·136
3	—	141·52	1121·6	109·4	1012·3	0·00845	118·5	·204
4	—	153·01	1126·5	120·9	1005·7	0·01107	90·5	·272
5	—	162·28	1130·5	130·1	1000·3	0·01364	73·33	·340
6	—	170·06	1133·7	137·9	995·8	0·01616	61·89	·408
7	—	176·85	1136·5	144·7	991·8	0·01867	53·56	·476
8	—	182·86	1139·0	150·8	988·2	0 02115	47·27	·544
9	—	188·27	1141·1	156·2	985·0	0·02361	42·36	·612
10	—	193·22	1143·1	161·1	982·0	0·02606	38·38	·680
14·7	—	212	1150·4	180	970·4	0·03732	26·79	1·000
15	0·3	213·0	1150·7	181·0	969·7	0·03806	26·27	1·021
20	5	228·0	1156·2	196·0	960·0	0·04980	20·08	1·361
25	10	240·1	1160·4	208·0	952·0	0·0614	16·30	1·701
30	15	250·3	1163·9	218·8	945·1	0·0728	13·74	2·041
35	20	259·3	1166·8	227·9	938·9	0·0841	11·89	2·382
40	25	267·3	1169·4	236·1	933·3	0·0953	10·49	2·722
45	30	274·5	1171·6	243·4	928·2	0·1065	9·39	3·062
50	35	281·0	1173·6	250·1	923·5	0·1175	8·51	3·402
55	40	287·1	1175·4	256·3	919·0	0·1285	7·78	3·742
60	45	292·7	1177·0	262·1	914·9	0·1394	7·17	4·08
65	50	298·0	1178·5	267·5	911·0	0·1503	6·65	4·42
70	55	302·9	1179·8	272·6	907·2	0·1612	6·20	4·76
75	60	307·6	1181·1	277·4	903·7	0·1721	5·81	5·10
80	65	312·0	1182·3	282·0	900·3	0·1829	5·47	5·44
85	70	316·3	1183·4	286·3	897·1	0·1937	5·16	5·78
90	75	320·3	1184·4	290·5	893·9	0·2044	4·89	6·12
95	80	324·1	1185·4	294·5	890·9	0·2151	4·65	6·46
100	85	327·8	1186·3	298·3	888·0	0·2258	4·429	6·80
105	90	331·4	1187·2	302·0	885·2	0·2365	4·230	7·14
110	95	334·8	1188·0	305·5	882·5	0·2472	4·047	7·49
115	100	338·1	1188·8	309·0	879·8	0·2577	3·880	7·83
120	105	341·3	1189·6	312·3	877·2	0·2683	3·726	8·17
125	110	344·4	1190·3	315·5	874·7	0·2791	3·583	8·50
130	115	347·4	1191·0	318·6	872·3	0·2897	3·452	8·85
135	120	350·3	1191·6	321·7	869·9	0·3002	3·331	9·19
140	125	353·1	1192·2	324·6	867·6	0·3107	3·219	9·53
145	130	355·8	1192·8	327·4	865·4	0·3213	3·112	9·87
150	135	358·5	1193·4	330·2	863·2	0·3320	3·012	10·21
155	140	361·0	1194·0	332·9	861·0	0·3425	2·920	10·55
160	145	363·6	1194·5	335·6	858·8	0·3529	2·834	10·89
165	150	366·0	1195·0	338·2	856·8	0·3633	2·753	11·23

TABLE XLIV.—*Continued.*

PROPERTIES OF SATURATED STEAM.

From Tables calculated by Lionel S. Marks and Harvey N. Davis, and published in 1909. Reproduced by permission of Messrs. Longmans, Green & Co.

Pressure in lbs. per sq. in. above vacuum.	Gauge pressure in lbs. per sq. in. (approx.)	Temperature in degrees F.	Total heat in heat units from water at 32° F.	Heat in liquid from 32° F. in heat units.	Heat of vaporization, or latent heat in heat units.	Density or weight of 1 cub. ft. in lbs.	Volume of 1 lb. in cubic feet.	Prsssure in atmospheres above vacuum.
170	155	368·5	1195·4	340·7	854·7	0·3738	2·675	11·57
175	160	370·8	1195·9	343·2	852·7	0·3843	2·602	11·91
180	165	373·1	1196·4	345·6	850·8	0·3948	2·533	12·25
185	170	375·4	1196·8	348·0	848·8	0·4052	2·468	12 59
190	175	377·6	1197·3	350·4	846·9	0·4157	2·406	12 93
195	180	379·8	1197·7	352·7	845·0	0·4262	2·346	13·27
200	185	381·9	1198·1	354·9	843·2	0·437	2·290	13·61
205	190	384·0	1198·5	357·1	841·4	0·447	2·237	13·95
210	195	386·0	1198·8	359·2	839·6	0·457	2·187	14·29
215	200	388·0	1199·2	361·4	837·9	0·468	2·138	14·63
220	205	389·9	1199·6	363·4	836·2	0·478	2·091	14·97
225	210	391·9	1199·9	365·5	834·4	0·489	2·046	15·31
230	215	393·8	1200·2	367·5	832·8	0·499	2·004	15·65
235	220	395·6	1200·6	369·4	831·1	0·509	1 964	15·99
240	225	397·4	1200·9	371·4	829·5	0·520	1·924	16·33
245	230	399·3	1201·2	373·3	827·9	0·530	1·887	16·67
250	235	401·1	1201·5	375·2	826·3	0·541	1·850	17·01
260	245	404·5	1202·1	378·9	823·1	0·561	1·782	17·69
270	255	407·9	1202·6	382·5	820·1	0·582	1·718	18·37
280	265	411·2	1203·1	386·0	817·1	0·603	1·658	19·05
290	275	414·4	1203·6	389·4	814·2	0·624	1·602	19·73
300	285	417·5	1204·1	392·7	811·3	0·645	1·551	20·41
310	295	420·5	1204·5	395·9	808·5	0·666	1·502	21·09
320	305	423·4	1204·9	399·1	805·8	0·687	1·456	21·78
330	315	426·3	1205·3	402·2	803·1	0·708	1·413	22·46
340	325	429·1	1205·7	405·3	800·4	0·729	1·372	23·14
350	335	431·9	1206·1	408·2	797·8	0·750	1·334	23·82
360	345	434·6	1206·4	411·2	795·3	0·770	1 298	24·50
370	355	437·2	1206·8	414·0	792·8	0·791	1·264	25·18
380	365	439·8	1207·1	416·8	790·3	0·812	1·231	25·86
390	375	442·3	1207·4	419·5	787·9	0 833	1·200	26·45
400	385	444·8	1208	422	786	0·86	1·17	27·22
410	395	447·2	1208	425	783	0·88	1·14	27·90
420	405	449·6	1208	427	780	0·90	1·11	28·58
430	415	452·0	1208	430	778	0·92	1·09	29·26
440	425	454·3	1208	433	776	0·94	1·06	29·94
450	435	456·5	1209	435	774	0·96	1·04	30·62
460	445	458·7	1209	438	771	0·99	1·01	31·30
470	455	460·9	1209	440	769	1·01	0·99	31·98
480	465	463·1	1209	443	767	1·03	0·97	32 66
490	475	465·2	1210	445	764	1·05	0·95	33·34
500	485	467·3	1210	448	762	1·08	0·93	34·02

Table No. XLV. sets out the usual sizes of pipes employed in feed-water systems. With the exception of column 2, the figures are taken from British Standard Specification No. 10/1904.

TABLE XLV.

STANDARD SIZES OF FEED PIPES.

Bore of pipe.	Thickness of pipe.	Diameter of flange.	Thickness of flange.	Radius of long bends.	Tees: centre to flange face.	Diameter of bolt circle.	No. of bolts.	Diameter of bolts.
ins.	ins.	ins.	ins.	ins.	ins.	ins.		ins.
2	$\frac{3}{16}$	6	$\frac{9}{16}$	6	5	$4\frac{1}{2}$	4	$\frac{5}{8}$
$2\frac{1}{2}$	$\frac{3}{16}$	$6\frac{1}{2}$	$\frac{9}{16}$	$7\frac{1}{2}$	$5\frac{1}{2}$	5	4	$\frac{5}{8}$
3	$\frac{1}{4}$	$7\frac{1}{4}$	$\frac{9}{16}$	9	6	$5\frac{3}{4}$	4	$\frac{5}{8}$
$3\frac{1}{2}$	$\frac{1}{4}$	8	$\frac{9}{16}$	$10\frac{1}{2}$	$6\frac{1}{2}$	$6\frac{1}{2}$	4	$\frac{5}{8}$
4	$\frac{1}{4}$	$8\frac{1}{2}$	$\frac{11}{16}$	12	7	7	4	$\frac{5}{8}$

Circulating Water Pipes.—The following Table, No. XLVI., gives the sizes of circulating water pipes. The smaller sizes up to a diameter of 30 inches are generally cast vertically from close-grained iron, and are specified to be of uniform thickness and smooth inside and out, and coated inside and out with Angus Smith's composition. In most cases such pipes are flanged, but there are places where an ordinary spigot and socket joint will do for low-level pipes not subject to any great head. In many cases riveted galvanized iron pipes should be used, especially if freight charges and difficulties of transportation have to be considered. Suction pipes are fitted with rose suction-boxes.

TABLE XLVI.

GALVANIZED IRON CIRCULATING WATER PIPING.

Bore of pipe.	Thickness of pipe.	Diameter of flange.	Thickness of flange.	Radius of long bends.	Tees: centre to face of flange.	Diameter of bolt circle.	No. of bolts.	Diameter of bolts.
ins.	ins.	ins.	ins.	ins.	ins.	ins.		ins.
14	$\frac{3}{8}$	$20\frac{3}{4}$	$1\frac{1}{2}$	63	17	$18\frac{1}{2}$	16	1
15	$\frac{3}{8}$	$21\frac{3}{4}$	$1\frac{1}{2}$	$67\frac{1}{2}$	18	$19\frac{1}{2}$	16	1
16	$\frac{3}{8}$	$22\frac{3}{4}$	$1\frac{5}{8}$	80	19	$20\frac{1}{2}$	16	1
18	$\frac{3}{8}$	$25\frac{1}{4}$	$1\frac{3}{4}$	90	21	23	20	1
20	$\frac{3}{8}$	$27\frac{3}{4}$	$1\frac{7}{8}$	110	23	$25\frac{1}{4}$	20	$1\frac{1}{8}$
21	$\frac{3}{8}$	29	$1\frac{7}{8}$	$115\frac{1}{2}$*	24	$26\frac{1}{2}$	24	$1\frac{1}{8}$
24	$\frac{3}{8}$	$32\frac{1}{2}$	$2\frac{1}{8}$	132*	27	$29\frac{3}{4}$	24	$1\frac{1}{4}$

From British Standard Specification No. 10/1904, excepting the figures marked *.

Condenser pipes of larger sizes are generally of riveted steel plate, but where possible it is better to incorporate concrete culverts in the foundations for the larger sizes of condensers. These may be constructed of reinforced concrete with a substantial saving of cement and other materials. The plan to be adopted depends on the relative position of the power house and river or source of condensing water. It will be better in some cases to use separate pipes for each condenser, and in other cases when the station is more distant from the water to construct concrete waterways.

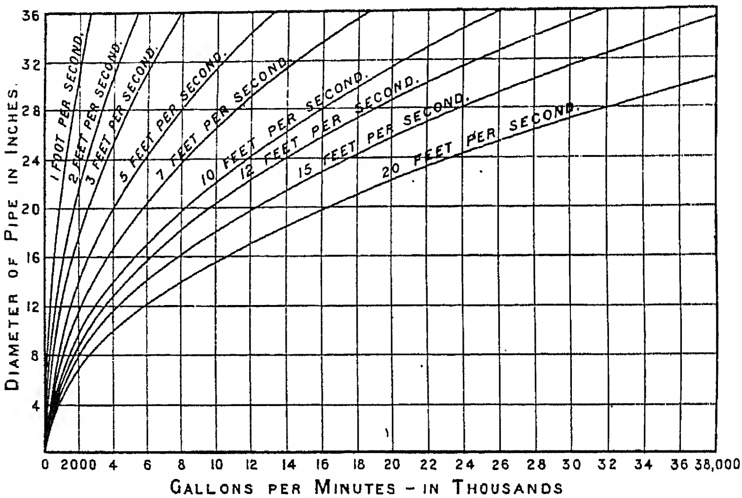


FIG. 45.

The curves given in Fig. 45 indicate graphically the quantity (gallons) of water delivered per minute at various velocities through pipes of various diameters.

It is usual to design the pipes for a water velocity of 5 feet per second, and this is good practice.

Rotary Strainers.—Where circulating water is drawn from a river or other source containing straw, grit, and other substances tending to choke the condenser tubes, etc., a rotary strainer of the type designed by Messrs. Bailey and Jackson of the City of London Electric Supply Co. can be adopted with a guarantee that such injurious "flotsam" will be strained off

and prevented from entering the circulating system. Fig. 46 shows one of these strainers. This consists of a casing in which is a wheel revolving very slowly and containing between its spokes sheet brass-strip grids so interlaced as to form small channels for the passage of the circulating water. The casing forms a chamber on both sides of the wheel, each chamber being

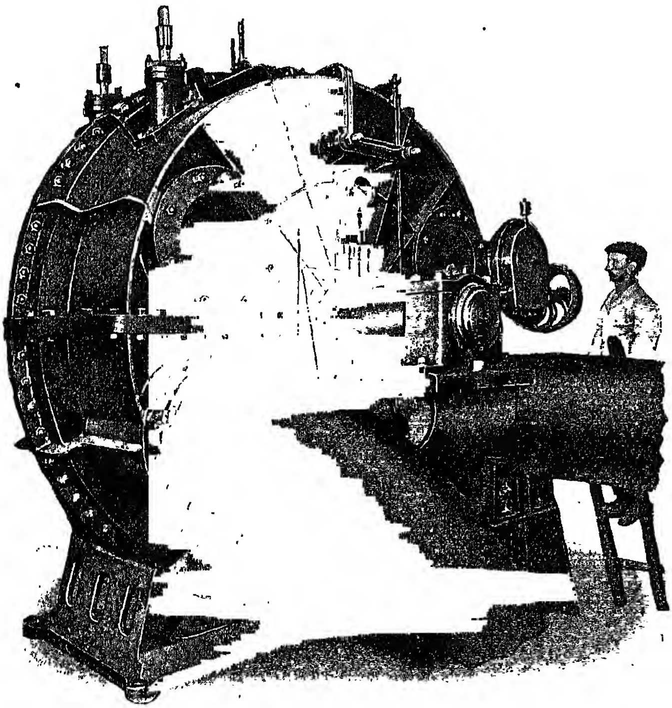


Fig. 46.

divided into two compartments by a partition. The first chamber receives the circulating water which is strained by being forced through the revolving grid. The return water, after passing through the condenser system, enters the other chamber and washes out the material caught up by the strainer, carrying it away with the discharge water.

Fig. 47 shows the lay-out of the circulating water-system designed for the Greenwich Power House. As will be seen,

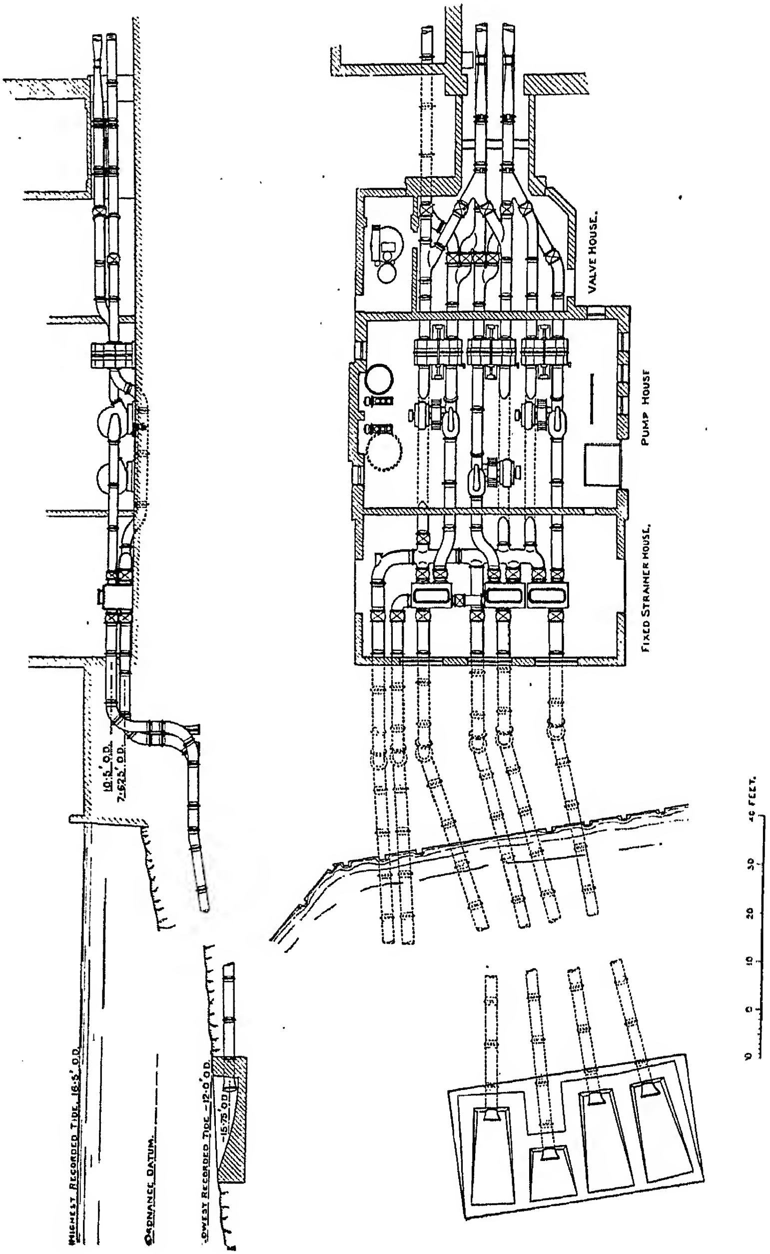

VALVE HOUSE.
PUMP HOUSE
FIXED STRAINER HOUSE.
10·5' O.D.
7·625' O.D.
HIGHEST RECORDED TIDE 18·5' O.D.
ORDNANCE DATUM.
OWEST RECORDED TIDE -12·0' O.D.
-15·75' O.D.
0
10
20
30
40 FEET.

FIG. 47.

the system includes rotary strainers together with pen-stocks and rough straining racks. The centrifugal pumps and cross-over pipes for alternate use on suction and discharge are also shown.

Exhaust Heads.—Atmospheric vent pipes should terminate in an exhaust head which serves two purposes; viz. to give the escaping steam a rotary motion in order to throw off some of the moisture contained in it against suitable baffles and thus prevent a nuisance to surrounding property; and, secondly, to prevent any chance of atmospheric vibration by decreasing the discharge velocity.

Pipe Supports and Anchors.—Wherever possible all hori-

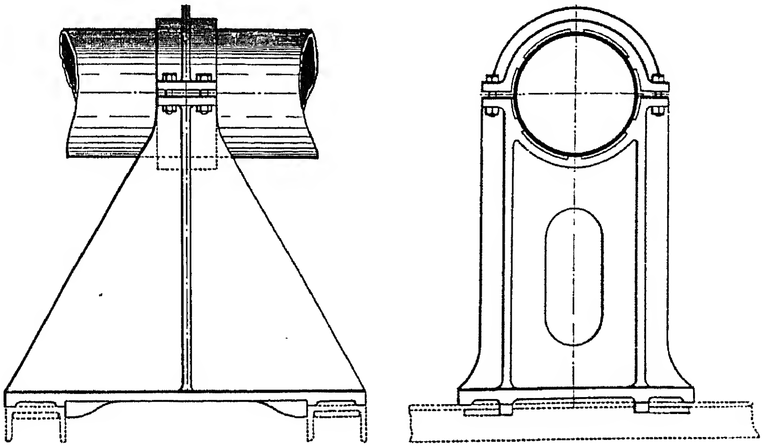


Fig. 48.

zontal lengths of pipe should be carried on rollers and supported from below. This is, of course, especially the case with the larger sizes of pipes. The rollers are carried on steel wall-brackets, or occasionally on columns, and should be mounted on set screws to ensure accurate setting up and levelling.

Cast-iron boxes with roller supports should be provided where pipes go through walls.

Heat-insulation pads should be inserted between the roller and the supporting bracket where the latter is bolted up to the steel structural framework of the building.

Anchoring is usually effected by brackets bolted up to the boiler-house stanchions as shown in Fig. 48. A slab of asbestos

should be inserted between the stool and the steel bracket so as to prevent conduction of heat. The remainder of the pipe is then carried on suitable rollers and brackets as mentioned above, and is thus free to move.

Anchor brackets are made up from steel channels and lattices, or cast, as shown in detail in Fig. 49.

It is better to avoid suspending pipes from swinging rods or straps, as these are less alignable than rollers. They are also more likely to set up stresses on pipe flanges owing to the extension of the rods, or to settlement, or to the giving of the ties or other

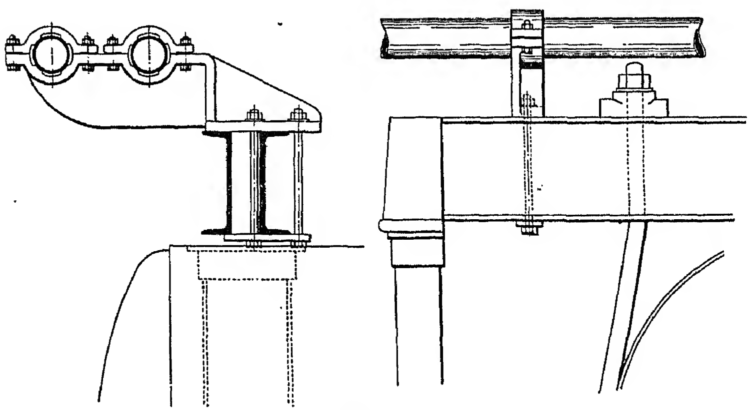


Fig. 49.

and less rigid parts from which they may be slung. Even if slung from brackets bolted up to the building structure, not so good a job is made as when the pipes are supported on brackets and rollers.

Exhaust Piping.—Exhaust pipes for small sets are usually made of cast iron; and for larger sets up to and including 8-inch pipes of lap-welded mild steel with steel flanges screwed and expanded on. Exhaust pipes above 8-inch in diameter should be made of riveted mild sheet steel (galvanized), with stout angle-iron flanges riveted to the pipe.

The following Table, No. XLVII., gives the normal dimensions of the usual sizes of exhaust pipes :—

TABLE XLVII.

STANDARD EXHAUST PIPING.

Bore of pipe.	Thickness of pipe.	Diameter of flange.	Thickness of flange.	Radius of long bends.	Tees: centre to face of flange.	Diameter of bolt circle.	No. of bolts.	Diameter of bolts.
ins.	ins.	ins.	ins.	ins.	ins.	ins.		ins.
2	$\frac{3}{16}$	$6\frac{1}{2}$	$\frac{7}{8}$	6	5	5	4	$\frac{5}{8}$
3	$\frac{1}{4}$	8	1	9	6	$6\frac{1}{2}$	8	$\frac{5}{8}$
4	$\frac{1}{4}$	9	$1\frac{1}{8}$	12	7	$7\frac{1}{2}$	8	$\frac{5}{8}$
5	$\frac{1}{4}$	11	$1\frac{1}{4}$	15	8	$9\frac{1}{4}$	8	$\frac{5}{8}$
6	$\frac{1}{4}$	12	$1\frac{1}{4}$	18	9	$10\frac{1}{4}$	12	$\frac{3}{4}$
7	$\frac{1}{4}$	$13\frac{1}{4}$	$1\frac{3}{8}$	$24\frac{1}{2}$	10	$11\frac{1}{2}$	12	$\frac{3}{4}$
8	$\frac{1}{4}$	$14\frac{1}{2}$	$1\frac{3}{8}$	28	11	$12\frac{3}{4}$	12	$\frac{3}{4}$
9	$\frac{5}{16}$	16	$1\frac{1}{2}$	$31\frac{1}{2}$	12	14	12	$\frac{3}{4}$
10	$\frac{5}{16}$	17	$1\frac{1}{2}$	40	13	15	12	$\frac{7}{8}$
12	$\frac{5}{16}$	$19\frac{1}{4}$	$1\frac{5}{8}$	48	15	$17\frac{1}{4}$	16	$\frac{7}{8}$
14	$\frac{5}{16}$	$21\frac{3}{4}$	$1\frac{3}{4}$	63	17	$19\frac{1}{2}$	16	1
15	$\frac{3}{8}$	$22\frac{3}{4}$	$1\frac{7}{8}$	$67\frac{1}{2}$	18	$20\frac{1}{2}$	16	1
16	$\frac{3}{8}$	24	$1\frac{7}{8}$	80	19	$21\frac{3}{4}$	20	1
18	$\frac{3}{8}$	$26\frac{1}{2}$	2	90	21	24	20	$1\frac{1}{8}$
20	$\frac{3}{8}$	29	$2\frac{1}{8}$	110	23	$26\frac{1}{2}$	24	$1\frac{1}{8}$
21	$\frac{3}{8}$	30	$2\frac{1}{4}$	$115\frac{1}{2}$*	24	$27\frac{1}{2}$	24	$1\frac{1}{8}$
24	$\frac{3}{8}$	$33\frac{1}{2}$	$2\frac{3}{8}$	132*	27	$30\frac{3}{4}$	24	$1\frac{1}{4}$

From British Standard Specification No. 10/1904, excepting the figures marked *. The Specification only gives the radius for sizes up to 20″ bore.

Exhaust Separators.—Table No. XLVIII. gives the standard dimensions of exhaust separators which are used in the exhaust pipes of reciprocating engines between the engine and its condenser. A small pump is used to withdraw the oil and water collected in the separator, and the discharge should be taken to a small skimming tank so as to recover the oil.

TABLE XLVIII.

STANDARD LIST OF OIL SEPARATORS.

Approximate indicated horse-power.	Lbs. of steam per hour.	Approximate diameter of exhaust pipe.	Diameter of shell of separator.		Height of shell of separator.		Face to face of flanges.		Approximate weight.
		ins.	ft.	ins.	ft.	ins.	ft.	ins.	tons.
125	2,500	6	3	0	3	6	4	2	0·6
150	3,000	6	3	0	4	0	4	2	0·75
175	3,500	6	3	3	4	0	4	6	0·775
200	4,000	7	3	3	4	3	4	6	0·8
250	5,000	7	3	3	4	6	4	6	0·9
300	6,000	8	3	6	5	6	4	9	1·25
400	6,750	9	3	9	5	9	5	0	1·35
500	7,500	10	4	0	6	0	5	6	1·75
550	8,250	10	4	0	6	6	5	6	1·8
600	9,000	11	4	3	6	3	5	9	1·9
700	10,500	12	4	3	7	0	5	9	2·15
800	12,000	14	4	6	7	0	6	0	2·35
850	12,750	15	4	6	7	6	6	0	2·4
900	13,500	16	4	6	8	0	6	0	2·5
1,000	15,000	18	4	9	8	0	6	3	2·7
1,100	16,500	18	5	0	8	0	6	6	2·8
1,200	18,000	19	5	3	8	0	6	9	2·95
1,300	19,500	20	5	6	8	0	7	0	3·1
1,400	21 000	21	5	9	8	0	7	3	3·4
1,500	22,500	22	6	0	8	0	7	6	3·5
1,750	26,250	22	6	6	8	0	8	0	4·0
2,000	30,000	24	6	6	9	0	8	0	4·1
2,250	33,750	24	6	9	9	0	8	3	4·25
2,500	37,000	26	7	3	9	0	8	9	4·75
2,750	41,250	28	7	6	9	0	9	0	5·0
3,000	45,000	30	7	6	10	0	9	0	5·45
3,500	52,500	32	8	0	10	0	9	6	5·95
4,000	60,000	34	8	3	11	0	9	9	6·55
5,000	75,000	36	9	0	11	6	10	6	8·1
6,400	96,000	38	9	9	12	6	11	3	11·75
10,000	150,000	40	11	0	15	0	12	6	13·25

CHAPTER VI

STEAM-ENGINE AND TURBO-GENERATORS

THE selection of the prime mover for any power house depends on the size of the plant and nature of the service. Bearing in mind the principle laid down in a preliminary chapter, that eight units represent the best number to install in a completed power house of large size, it is comparatively easy to determine the size of each individual unit. This must not be taken as a hard-and-fast rule, but it may be worked to as an approximate one. With eight sets, one can be dismantled, another can be standing by, and six can be working at rated load, or five at load and a quarter. There is thus 75 per cent. of the installed plant which can be safely ranked as revenue producing. The factors to be considered when fixing the type of plant are—size; type of generator, whether direct current or alternating; geographical position of power house, accessibility for material and also for skilled repairs; and nature of service, i.e. whether general power and lighting supply, tramway, or railway supply, and so forth.

Broadly speaking, the tendency of modern practice is to use reciprocating engines in electrical power houses when the size of unit does not exceed 750 K.W. output, especially with direct-current generators, having regard to economical speeds; and to use turbines always for larger units.

Reciprocating engines are divided empirically into high-speed, medium-speed, and low-speed classes. The high-speed are those with speeds varying from 250 to 625 R.P.M. and with piston speeds of about 750 feet per minute. The slow-speed sets usually run at from 83 to 107 R.P.M. with a piston speed of 750 feet per minute.

The following Table, No. XLIX., sets forth the relative

speeds, weights, approximate pre-war costs, and steam consumptions of the various types of reciprocating engine plant. The prices must, of course, be only taken as relative since the conditions of any particular contract and many other things arise to vary them. The relative figures, however, will serve for comparison.

TABLE XLIX.

COMPARATIVE DATA FOR RECIPROCATING ENGINE PLANT.

Type.	Rated output.	Speed.	Total weight of engine.	Weight per B.H.P.	Weight of fly-wheel.	Steam consumption. Full load. 27 ins. vac.	Approximate costs (pre-war). Engine: total.	Engine and generator: total.	Engine: per B.H.P.	Engine and Generator: per K.W.	Floor space per K.W.
	B.H.P.	R.P.M.	tons.	tons.	tons.	lbs.	£	£	£	£	sq. ft
Slow-speed	5,300	94	280	0·053	40	16·88	22,600	29,250	4·26	8·00	0·46
Medium-speed	2,000	188	110·00	0·055	17	17·01	6,046	11,296	3·02	7·53	0·21
do.	1,500	188	69·00	0·046	13	17·62	5,162	9,587	5·16	8·56	0·25
do.	1,100	188	54·00	0·050	12	17·75	2,900	6,500	4·60	8·25	0·30
High-speed	1,450	250	68·35	0·047	11	17·60	3,903	8,180	2·69	7·58	0·24
do.	1,100	250	49·25	0·044	10	17·75	2,647	5,892	2·40	7·18	0·28
do.	570	375	14·50	0·025	5	19·40	1,284	3,965	2·25	9·32	0·30

The necessity for reducing capital expenditure on power houses to a minimum consistent with sound commercial results and for avoiding waste is nowadays universally recognized. These considerations really restrict the choice of modern plant to high-speed reciprocating sets for smaller sizes, and to turbines for the larger sizes. The Author does not therefore propose to enter into a lengthy description of the slow-speed horizontal, vertical, or "grasshopper" types of engine, since (*a*) their greater cost, (*b*) greater weight, affecting foundations, (*c*) greater floor space, affecting the size and cost of buildings, and (*d*) the greater cost of attendance, really put this type out of court except in very special circumstances. Excellent work has been done in the past by such engines, and low steam consumption

and low cost of repairs can certainly be claimed for any of those made by first-class engine builders. Except, however, in the case of direct-current generators of larger sizes—which are becoming increasingly rare—the large size slow-speed engine will probably never again be used in future power houses, or in extensions of existing ones.

The high-speed engine will, however, probably long be retained for small units of plant. The Author suggests that from 750 to 1000 K.W. is the limit beyond which all present considerations of cost and general economy require the adoption of steam turbines.

The following Table, No. L., extracted from British Standard Specification No. 42/1921 (not yet approved), gives the sizes and standard speeds of reciprocating engines for a frequency of 50 cycles.

TABLE L.

RECIPROCATING ENGINES: SIZES AND STANDARD SPEEDS.

Rated output in K.W.	Approximate B.H.P.	Revolutions per minute at rated output for 50 cycles.		
		Slow.	Medium (throttle governing).	High (throttle governing).
100	134	125	250	500
150	201	125	250	428
200	268	125	250	428
250	335	125	250	428
300	402	125	214	375
400	536	107	214	375
500	670	107	214	300
750	1,100	107	188	300
1,000	1,340	107	188	250

In these figures the full load of the steam engine expressed in K.W. is assumed to be 110 per cent. of the rated load of the generator. The rated load of the generator is the output at which it will work continuously for six hours, within the limits of certain defined temperature rises, viz. 60° C. in stationary and moving coils when measured by resistance, and 50° C. in moving coils when measured by thermometer, assuming the air temperature in the test-room not to exceed 25° C.

The advantages of high-speed sets are, reduction in the size

of generator, compactness, small floor space required, and small weight per H.P. (see Table No. XLIX.). They are always arranged with a self-oiling system, and are throttle governed with an auxiliary automatic cut-off. Engines up to 500 K.W. are usually of the compound type, and above 500 K.W. are arranged for triple expansion. This, of course, also depends on the steam pressure available at the stop valve. Willans, in his classic paper read before the Institution of Civil Engineers (vol. xciii.), showed that triple-expansion engines became more economical when the stop valve pressure exceeded 160 lbs. Steam jacketing is found to be unnecessary, owing to the high revolutions per minute. A large fly-wheel is invariably fixed, and the recommendation is that this, plus the weight of the generator rotor, shall be such that the cyclic irregularity, i.e. the maximum permissible variation in speed of the generator throughout one revolution, shall not exceed $\frac{1}{30}$th of the angle between two poles. That is to say, the permissible variation in the amount by which the rotating part forges ahead plus the amount it lags behind the position of uniform rotation shall not exceed 6° in a two-pole machine, 3° in a four-pole machine, and 1·2° in a ten-pole machine. Increased fly-wheel effect has to be given to engines designed for colliery, winding, and traction work.

Fig. 50 shows a typical engine built to the Author's general specification for a remote part of South America where only locomotive fitters were available and turbine repairs would have been difficult to carry out. This engine is rated at 1500 B.H.P. continuously at a speed of 188 R.P.M., with steam at an initial pressure of 180 lbs. per square inch, superheated 56° C. (absolute temperature of steam 247° C.) and exhausting into a 26-inch vacuum. The principal features of this set (which may be taken as typical of all well-built, high-speed sets) are: triple expansion, the dimensions of the cylinders being $21\frac{1}{2}'' \times 34'' \times 54'' \times 24''$ stroke; ratio of connecting rod to stroke 1 : 2·75; floor space 0·2 square feet per B.H.P.; throttle governed, with automatic cut-off gear driven through a steam relay and acting on a rifled liner; motor-speeding gear for paralleling purposes; duplicate oil-pumps and strainers; water-cooling pipes for crank chamber; tail rods to each cylinder; heavy fly-wheel proportioned to the

revolving masses and inertia diagram of the engine; low steam consumption, and interchangeability of parts with sister engines. The steam consumptions guaranteed, in pounds of water per kilowatt-hour measured at the alternator terminals, and at unity power factor, when working under the specified conditions of

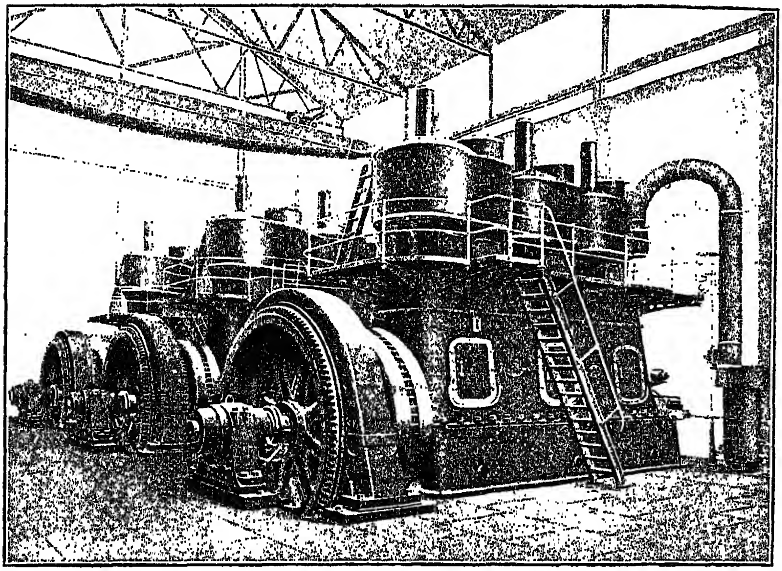


Fig. 50.

steam pressure (180 lbs.), superheat (100° Fahr.), and vacuum (26 inches), were as follows :—

One and a quarter load.	Full load.	Three-quarter load.	Half load.	Quarter load.
lbs. 17·68	lbs. 17·58	lbs. 18·14	lbs. 19·15	lbs. 22·99

The pistons of the high-pressure and intermediate-pressure cylinders are of cast iron, but the low-pressure piston is made of wrought steel. The piston and valve rods, which are $5\frac{3}{4}$ inches and 3 inches in diameter respectively, are made of crucible cast steel, and are all fitted with United States metallic packing.

There is no soft packing-gland in the engine. The cylinders are mounted on distance-piece castings, in which the exhaust branches are formed. A metallic scraper gland is fitted to all rods, at the top of the frame, to prevent oil from the crank chamber being drawn upwards, and at the same time to prevent leakage from the cylinder glands getting into the crank chamber.

The crank shaft is made from a solid forging of acid mild steel with a tensile strength of 28·32 tons, and an elongation of 25 per cent. in a test length of 8 inches. Balance-weights are fitted to all cranks. The fly-wheel, which weighs 13 tons, is bolted to a large coupling forged solid with the shaft, the same bolts being used for attachment to the alternator coupling.

Governing is effected by the control of the throttle-valve in the usual way, and also by means of an automatic expansion gear which is fitted to the high-pressure cylinder. The centrifugal governor is fixed on the end of the crank shaft and is directly connected to the throttle-valve through a bell-crank lever. In addition, the governor is connected to the automatic expansion gear through a second arm of the bell-crank lever, as shown in Fig. 51. The expansion gear varies the cut-off in the high-pressure cylinder from 40 to 85 per cent. of the stroke, according to the load on the engine. The alteration in cut-off is effected by slightly rotating the high-pressure valve, which has angular ports, and works across corresponding angular ports in the liner. By means of this rotation, the lead of the valve and the cut-off are varied. The engine speed can be varied 5 per cent. up or down while the engine is running, and a speeder gear is fitted which is operated by an electric motor fixed above the governor casing. The motor can be started, stopped, and reversed by means of a two-way switch on the switchboard, and a knock-out gear is fitted to prevent over-winding in either direction.

Forced lubrication is supplied to all working parts, including the governor, by two valveless oil pumps worked from the low-pressure valve eccentric. These pumps are fitted in a trough below the bed-plate which extends some distance beyond the back of the engine, and is fitted with hinged doors arranged to lift upwards for giving access to the oil-strainers, through which

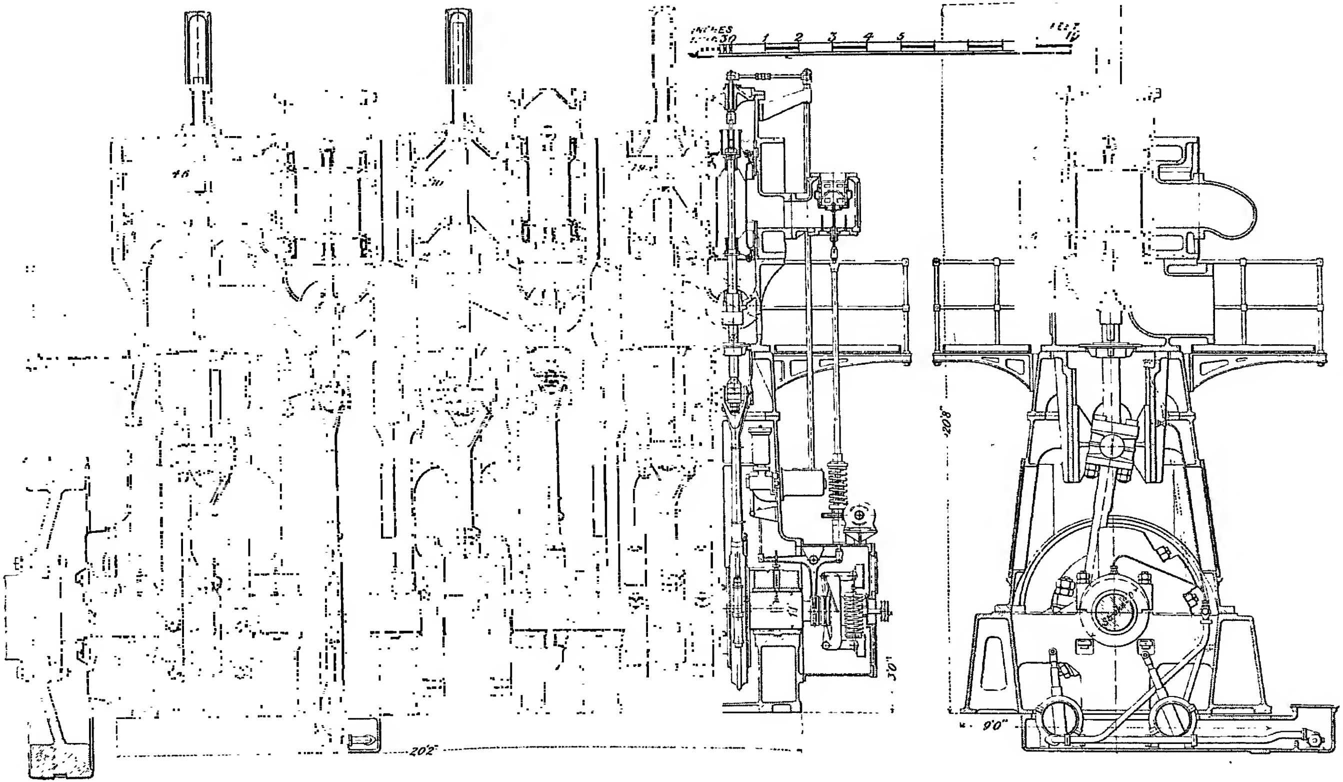


FIG. 51.

all the oil is drawn before being delivered to the working parts. Two strainers are fitted, one for each pump, and as each pump is of sufficient capacity to lubricate the engine, either of the strainers may be removed for cleaning without affecting the

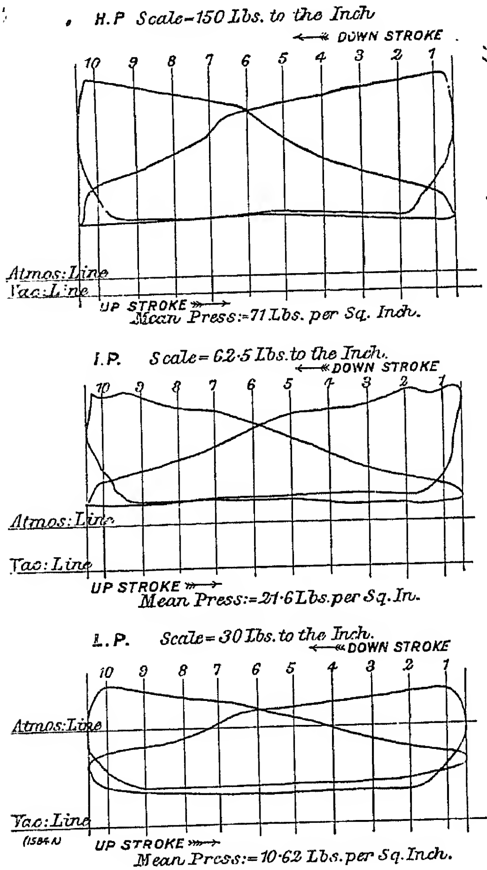


FIG. 52.

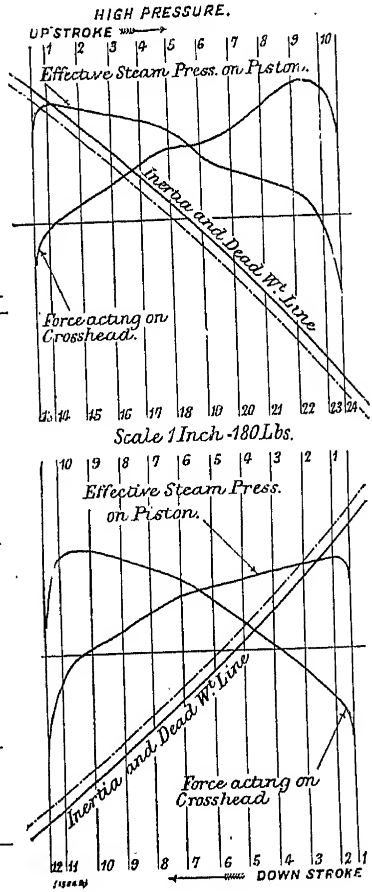


FIG. 53.

running. A valve is fitted which automatically shuts off the oil from the pump when a strainer is removed, and so prevents grit being drawn into the oil-pipes if the engine is running when the strainer is taken out.

Fig. 52 shows a set of indicator diagrams taken at full load,

while Figs. 53, 54, and 55 give a turning effort diagram and curves of cross-head forces, which should be of interest. In Figs. 53, 54, and 55, the chain-dotted curves represent the

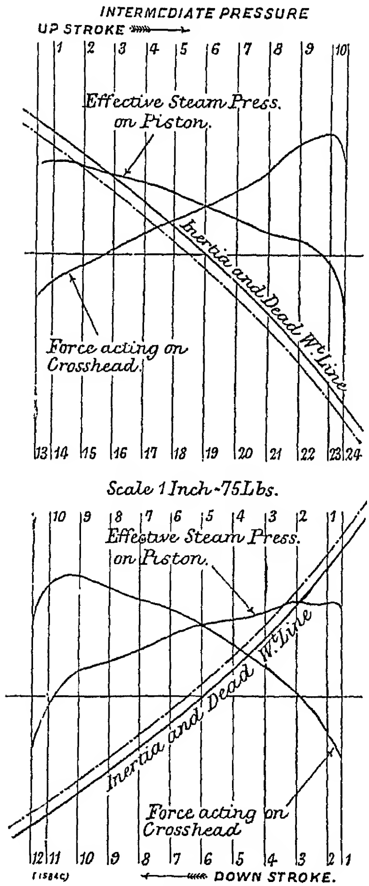


FIG. 54.

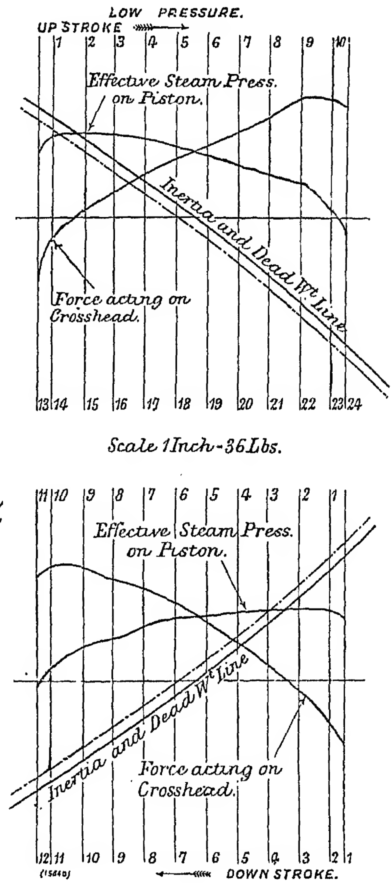


FIG. 55.

inertia, while the full lines parallel to these curves represent the same thing with the addition or subtraction of the constant dead-weight.

Fig. 56 is a curve of the combined turning effort, in which the—

Scale of lbs. is 1 inch to 80,000.

Scale of crank-pin travel $\frac{3}{4}$ inch = 1 foot.

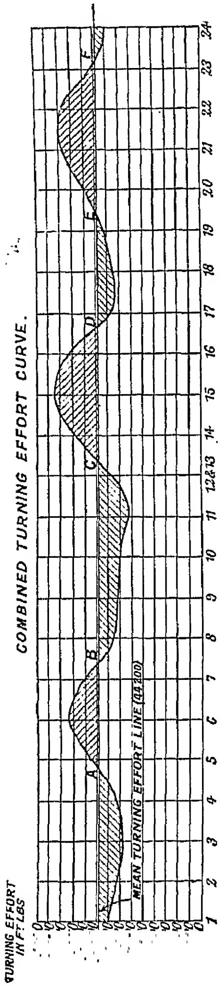


Fig. 56.

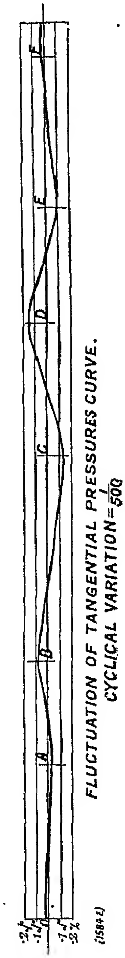


Fig. 57.

Scale of tangential pressure $= \dfrac{\text{turning moments}}{\text{length of crank}} =$ 80,000 to 1 inch.

Scale of work done = $80,000 \div \frac{3}{4} = 106,666$ foot-lbs. to each square inch of area enclosed by curve.

Fig. 57 is a curve showing the fluctuation of tangential pressures, the cyclical variation being 1 in 500.

Fig. 58 shows some 1500 K.W. Belliss and Morcom sets installed at the Summer Lane Power House, Birmingham, England. These engines represent the highest and best practice, and are working in all parts of the world.

The sets have a continuous output of 1500 kilowatts, with a 25 per cent. overload for short periods of time, running at 160 revolutions per minute, and using steam at 180 lbs. pressure. They have an output of 2140 B.H.P. normal, and 2680 B.H.P. maximum, the cylinder sizes being 25 inches, $36\frac{1}{2}$ inches, and 55 inches diameter by 33 inches stroke. Piston valves are fitted to all cylinders, the valve gear being of the single eccentric type. Automatic expansion gear is fitted to all the engines, the cut-off of the high-pressure slide valve being varied by means of a special relay cylinder, operated

from the same governor that works the throttle-valve. On this plan the governing is by automatic expansion at the higher loads

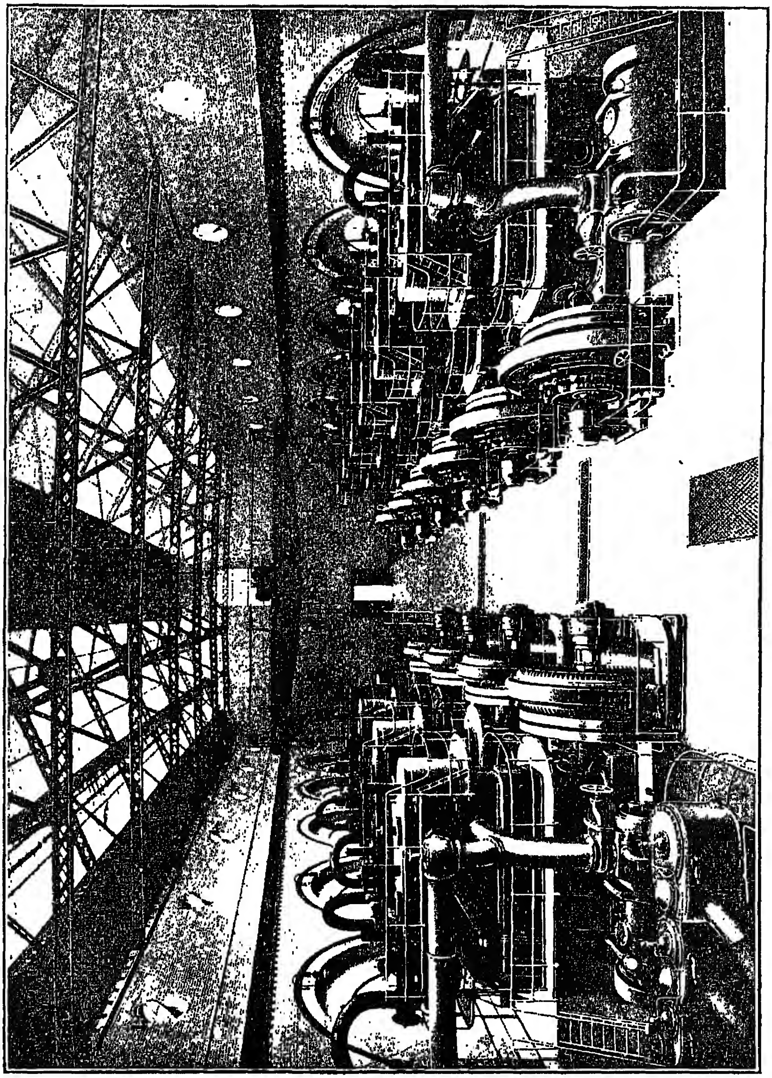


FIG. 58.

and by the throttle at the lower loads, an arrangement which experience has shown to give the most economical performance with high-speed engines.

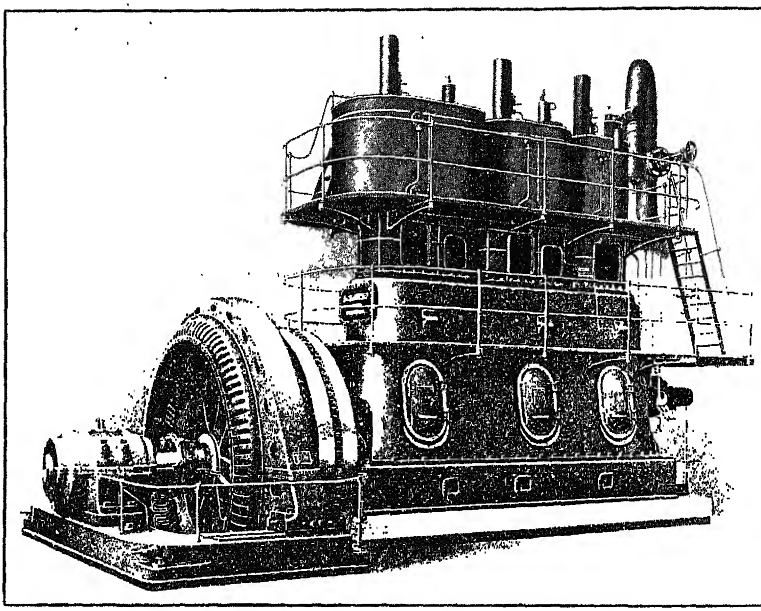


FIG. 59.

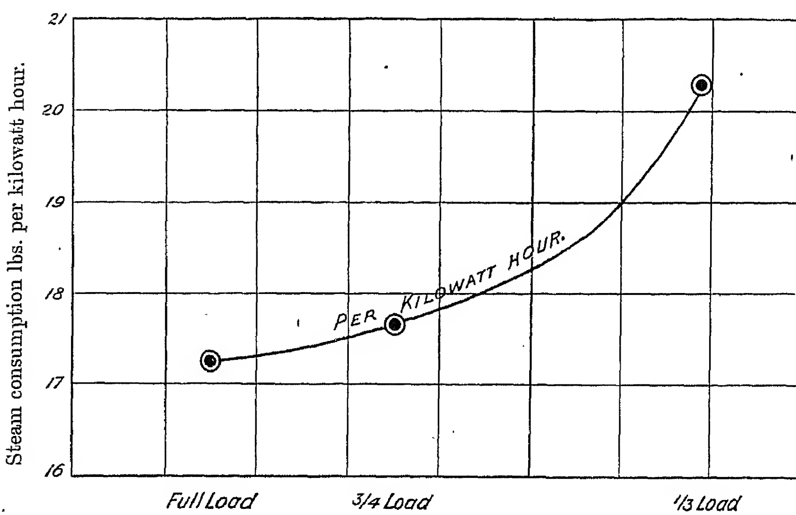

21
20
19
18
17
16
Steam consumption lbs. per kilowatt hour.
PER KILOWATT HOUR.
Full Load
3/4 Load
1/3 Load

FIG. 60.

Fig. 59 shows the general arrangement of one of these engines, and Fig. 60 gives the steam consumption guaranteed.

Table No. LI. gives the dimensions, weights, and approximate prices of standard high-class compound and triple expansion engines. The prices given are on a pre-war basis and are approximate covering prices for estimating purposes only.

TABLE LI.

APPROXIMATE DIMENSIONS, WEIGHTS, ETC., OF TWO-CRANK COMPOUND DOUBLE-ACTING, QUICK-REVOLUTION, FORCED-LUBRICATION ENGINES.

Output.	Length.	Width.	Height.	Weight.	Weight of heaviest lift.	Speed.	Approximate price engine only. (Pre-war.)
K.W.	ft. ins.	ft. ins.	ft. ins.	T. C.	T. C.	R.P.M.	£
50	5 3	3 8	6 6¼	2 15	2 15	575/600	288
75	5 3	3 8	6 8¼	3 5	1 14	400/525	323
100	6 3½	4 2	8 3	5 10	2 15	475/500	388
150	7 2½	4 6	8 9	7 0	3 0	428/435	470
200	7 11	5 3	9 6	9 15	3 15	375	602
300	8 5¾	5 4½	10 0	12 12	4 0	375	721
400	8 11½	5 6¼	10 6	14 10	4 10	350/375	822

APPROXIMATE DIMENSIONS, WEIGHTS, ETC., OF TRIPLE EXPANSION, DOUBLE-ACTING, QUICK-REVOLUTION, FORCED-LUBRICATION ENGINES.

Output.	Length.	Width.	Height.	Weight.	Weight of heaviest lift.	Speed.	Approximate price engine only. (Pre-war.)
K.W.	ft. ins.	ft. ins.	ft. ins.	T. C.	T. C.	R.P.M.	£
300	12 7½	6 0	10 10	17 8	5 5	375	1,069
400	13 5¾	6 0	11 7	23 3	6 15	375	1,284
500	14 8¾	6 6	13 9	29 2	7 10	333	1,593
750	18 5½	7 11	18 0	49 5	11 6	250	2,647
1000	20 11¼	7 6	18 7	68 7	12 0	250	3,903
1500	25 11	8 0	24 0	110 0	20 5	188	6,046

There are several practical points to be considered when specifying reciprocating engines for power-house work; for example, the size of unit, the maker's standards of speed, and also the frequency of the system if alternating current. The steam-range pressure will probably be fixed from 180 to 200 lbs., and a moderate superheat of, say, 100° Fahr. adopted.

The principal details with which an engineer has to concern himself are:—

(*a*) Steam consumption guaranteed, with which he will have no difficulty with any well-known maker.

(*b*) Weight of fly-wheel and rotor, and guaranteed maximum limit of cyclic irregularity.

(*c*) Governor trials and freedom from hunting, so as to enable machines to be run in parallel without trouble. The maximum temporary increase or reduction of speed due to suddenly throwing off the whole load not to exceed 10 per cent. of the standard speed, and the continuing alteration in speed not to exceed 5 per cent. The maximum temporary variation in speed due to the load being varied gradually, or by steps not exceeding 20 per cent. of the rated load, not to exceed 5 per cent. of the standard. For large stations, a motor-driven speed-adjusting gear operated from the switchboard is often a convenience.

(*d*) Duplicate oil pumps for the forced-lubrication system for the larger engines, say, over 500 H.P.; the selection of a proper oil to suit the running conditions of the engine; and, if necessary, the adoption of a water-circulating system for the crank chamber.

(*e*) Grouping of all gauges and drain handles at the driving end, so as to be accessible and under the view of the engine-driver.

(*f*) Suitability of white metal composition for the particular engine bearings and climatic conditions of running.

(*g*) Careful selection of the metallic packings for the piston and valve-rod stuffing boxes, and also of the piston rings—particularly for the high-pressure end.

(*h*) Fixing of suitable relief valves and cocks for indicator gear not only on the cylinders but also on the receivers.

(*i*) Suitable ladders and platforms for the larger engines for access to the packings and lubricators on the cylinder tops and for convenience of inspection and overhaul.

(*j*) Careful balancing of engine.

(*k*) Interchangeability of parts with sister engines. This is most important with regard to the stock of spare parts and

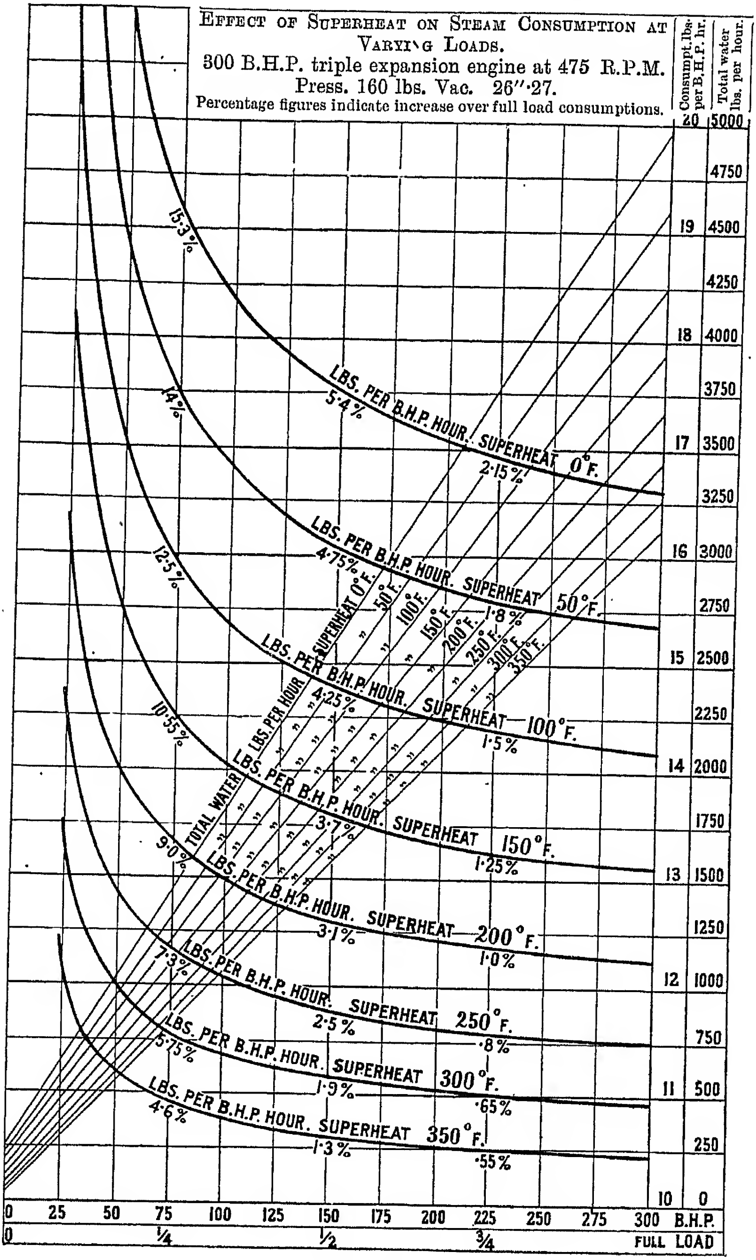

EFFECT OF SUPERHEAT ON STEAM CONSUMPTION AT VARYING LOADS.
300 B.H.P. triple expansion engine at 475 R.P.M.
Press. 160 lbs. Vac. 26″·27.
Percentage figures indicate increase over full load consumptions.
Consumpt. lbs. per B.H.P. hr.
Total water lbs. per hour.
LBS. PER B.H.P. HOUR. SUPERHEAT 0°F.
LBS. PER B.H.P. HOUR. SUPERHEAT 50°F.
LBS. PER B.H.P. HOUR. SUPERHEAT 100°F.
LBS. PER B.H.P. HOUR. SUPERHEAT 150°F.
LBS. PER B.H.P. HOUR. SUPERHEAT 200°F.
LBS. PER B.H.P. HOUR. SUPERHEAT 250°F.
LBS. PER B.H.P. HOUR. SUPERHEAT 300°F.
LBS. PER B.H.P. HOUR. SUPERHEAT 350°F.
TOTAL WATER LBS. PER HOUR SUPERHEAT 0°F. 50°F. 100°F. 150°F. 200°F. 250°F. 300°F. 350°F.
15·3% 5·4% 2·15%
14% 4·75% 1·8%
12·5% 4·25% 1·5%
10·55% 3·7% 1·25%
9·0% 3·1% 1·0%
7·3% 2·5% ·8%
5·75% 1·9% ·65%
4·6% 1·3% ·55%
20 19 18 17 16 15 14 13 12 11 10
5000 4750 4500 4250 4000 3750 3500 3250 3000 2750 2500 2250 2000 1750 1500 1250 1000 750 500 250 0
0 25 50 75 100 125 150 175 200 225 250 275 300 B.H.P.
0 ¼ ½ ¾ FULL LOAD

FIG. 61.

especially for remote situations abroad. It is also desirable that engines of the same size should also be to the same hand, if possible, in the interests of duplication.

(*l*) The engine to be capable of driving the generator continuously at all loads up to the rated output, and also at 25 per cent. above rated output for a period of two hours, without undue heating of the bearings or other mechanical trouble.

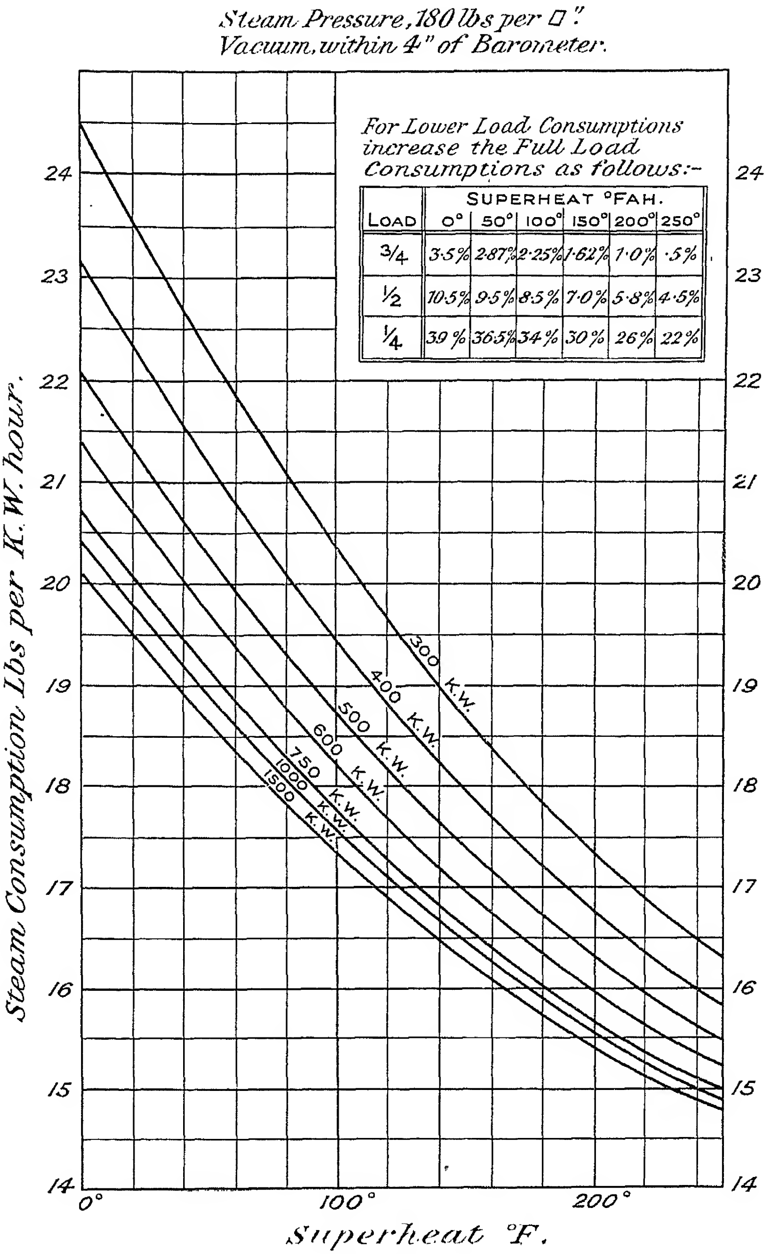
Fig. 61 represents the results of some elaborate tests made by Messrs. Belliss and Morcom on a triple expansion engine to determine the effect of various degrees of superheat at various loads. The reduction in steam consumption due to the increase of superheat is shown, and also the flattening effect due to the superheat. At the time of these tests the engine was not fitted with the automatic expansion gear with which all the larger engines made by this company are now fitted, otherwise the steam consumption at the various loads would have approximated even more closely at the higher superheats than the curve shows them to do.

These curves are useful on steam trials to read off the percentage variation in steam consumption due to any variation in superheat.

Fig. 62 shows the approximate full-load steam consumptions per K.W. hour for triple-expansion, double-acting engines, when exhausting into a condenser vacuum within 4 inches of the barometer.

The curves show the variation between no superheat and 250° Fahr. superheat. A table is also appended to the figure giving the correction for the fractional loads.

In order to obtain the approximate full-load steam consumption under non-condensing conditions, add 30 per cent. to the values given in the curves shown in Fig. 62. The following Table, No. LII., gives the approximate percentage increase at lower loads non-condensing :—



Load	Superheat °Fah. 0°	50°	100°	150°	200°	250°
3/4	3·5%	2·87%	2·25%	1·62%	1·0%	·5%
1/2	10·5%	9·5%	8·5%	7·0%	5·8%	4·5%
1/4	39 %	36·5%	34 %	30 %	26%	22%

Fig. 62.

TABLE LII.

Percentage Increase on Full-load Non-condensing Figures, Showing the Increased Steam Consumption at Fractional Loads Non-condensing. Full-load Steam Pressure from 150-180 lbs. per square inch.

Superheat (degrees Fahr.).	0°	50°	100°	150°	200°	250°
$\frac{3}{4}$-load . .	6·5	5·5	4·75	4·1	3·5	2·7
$\frac{1}{2}$-load . .	20·5	19·0	17·5	16·0	14·0	12·0
$\frac{1}{4}$-load . .	76·0	71·0	65·0	58·0	50·0	41·0

Fig. 63 shows the steam consumption per K.W. hour at full load of compound double-acting engines with an initial steam pressure of 150 lbs. per square inch, and under the same conditions of superheat and vacuum as in the case of Fig. 62.

Turbines.—The development of turbines has been most rapid. Broadly they may be divided into three practical classes.

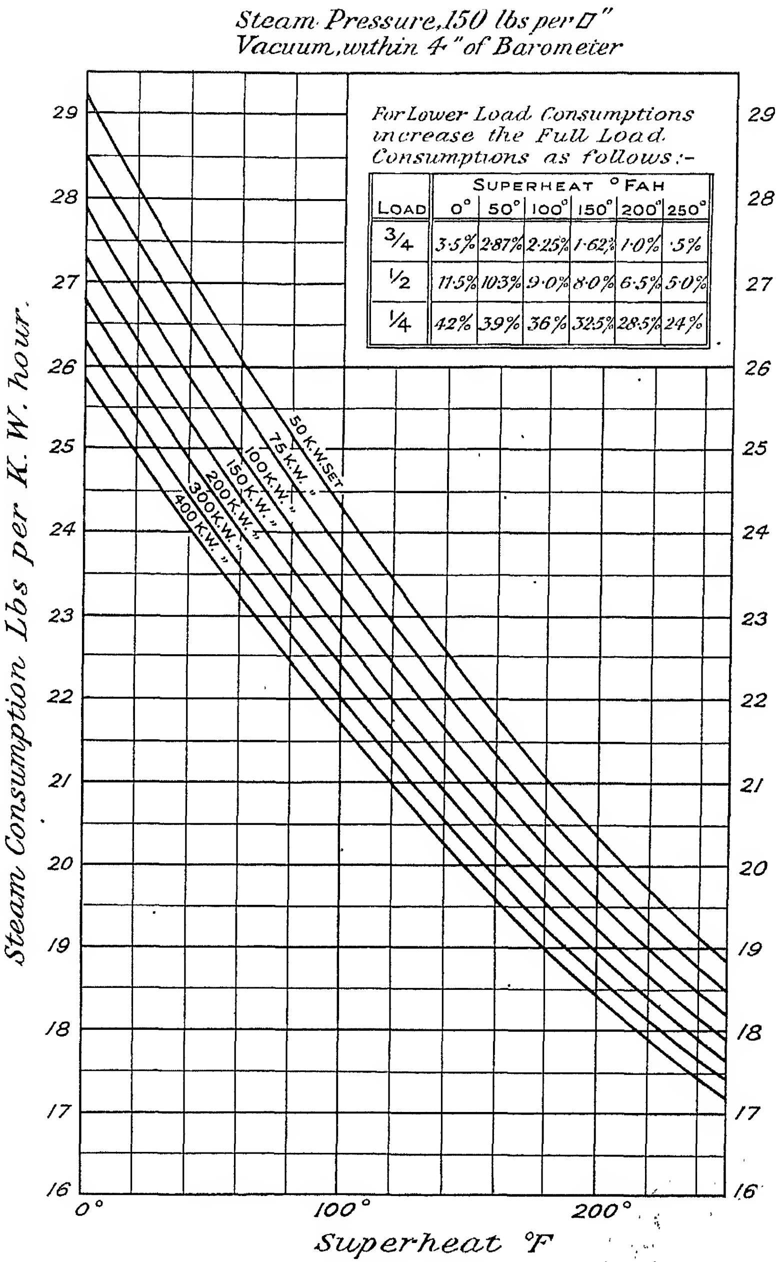
(*a*) The impulse type, such as the Curtis, Zoelly, Rateau, and others, with only a few stages of expansion.

(*b*) The reaction type, such as the Parsons and derivatives of that design, with fifty or more stages of expansion.

(*c*) A combination type, such as the Belliss and Morcom and others, with an impulse or velocity wheel which reduces the initial pressure approximately to that of the atmosphere, and reaction blades for the remainder of the expansion.

In the impulse type the steam is admitted to the turbine through expanding nozzles, and on leaving the directing nozzle impinges on specially shaped buckets fixed on a revolving disc or wheel. The different makes, which are variables of design and not of principle, will be briefly described hereunder.

In the reaction type the steam is admitted at the high-pressure end through fixed vanes, which guide the steam in the right direction so that it flows through properly inclined blades fixed on the turbine rotor. The sizes and clearances of the vanes and blades increase towards the exhaust end as the pressure of the steam decreases and the volume increases. In some cases, as in the Westinghouse turbine, steam is admitted in the middle and flows right and left to the low-pressure ends, giving what is known as a double flow, balancing the turbine,



Load	Superheat °Fah 0°	50°	100°	150°	200°	250°
3/4	3·5%	2·87%	2·25%	1·62%	1·0%	·5%
1/2	11·5%	10·3%	9·0%	8·0%	6·5%	5·0%
1/4	42%	39%	36%	32·5%	28·5%	24%

FIG. 63.

and thus removing end thrust. In the single flow turbines this end thrust has to be compensated for by dummy pistons, against which live steam impinges. In this type the clearances are very minute, and great care has to be exercised when warming or running up any set, so as to prevent one side getting more heat than the other, and thus causing deformation in the rotor spindle.

Economy of Turbines.—The economy of turbines is three-fold: first, the steam consumptions are lower than those of any of the best reciprocating sets providing a high vacuum is obtainable, and no oil is required in the turbine cylinders; secondly, their capital cost per unit of capacity for sizes above 750 K.W. is increasingly less as their size increases; thirdly, the floor space occupied is also very much smaller, entailing less cost of buildings and foundations.

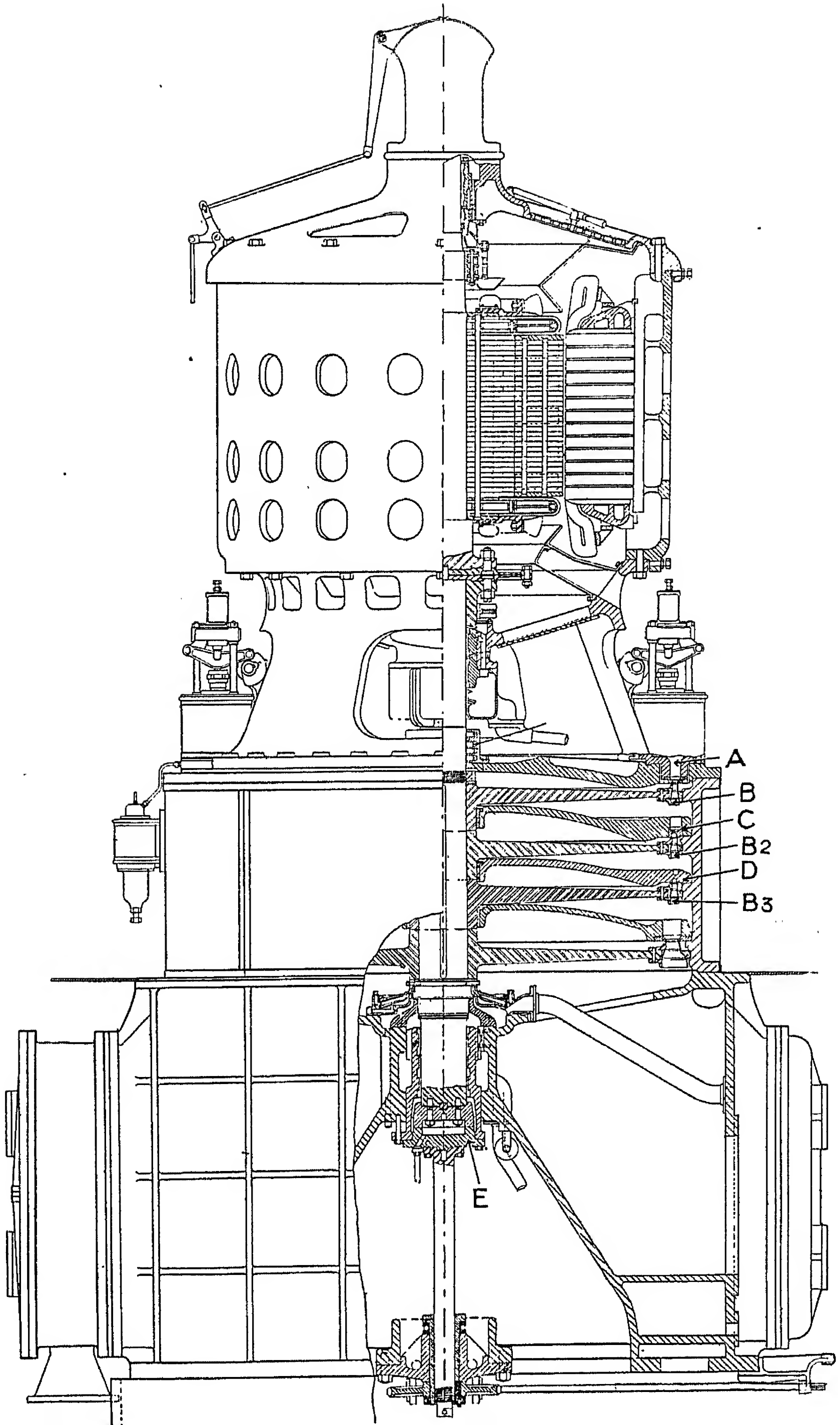
It must, however, be borne in mind that as the economy of a turbine is entirely dependent on the maintenance of a high vacuum, the cost of a larger condenser has to be included together with a more liberal allowance of circulating water.

Thus, especially in the smaller plants, and more especially where auxiliary cooling towers have to be adopted, it is fair to compare not the prices and performances of engine or turbine alone, but each with its added condenser and condenser auxiliaries. More will be said about this in the condenser section. (See also Fig. 92.)

Speed of Turbines.—In alternating work, a frequency of 50 ∽ fixes the speeds at 750, 1500, or 3000 R.P.M. for 8, 4, and 2-pole generators respectively. Turbines up to a capacity of 18,750 K.W. are now built for a speed of 3000 R.P.M., and of a capacity of 20,000 K.W. (40 cycles) for a speed of 2400 R.P.M.

Turbines are now constructed with rotors having a peripheral speed of about 33,000 feet per minute. Any increase above this figure must obviously reduce the factor of safety in the ultimate strength of the revolving materials and, in the Author's opinion, is inadvisable.

The following descriptions of the principal types will be useful to the designer. For more detailed information reference


A
B
C
B2
D
B3
E

should be made to the various well-known books on the Steam Turbine, such as those by Jude, Stodola, and others.

Impulse Turbines.—The advantages of impulse type turbines are the greater mechanical strength of construction, and the greater clearances of rotating parts. The peripheral velocity can be kept within safe limits by increasing the number of wheels, and the steam curves are as good as those obtained with the reaction type. Great care has to be exercised in proportioning the sections of the rotating masses, and the greatest precision can be made in the accurate machining and fitting of the buckets

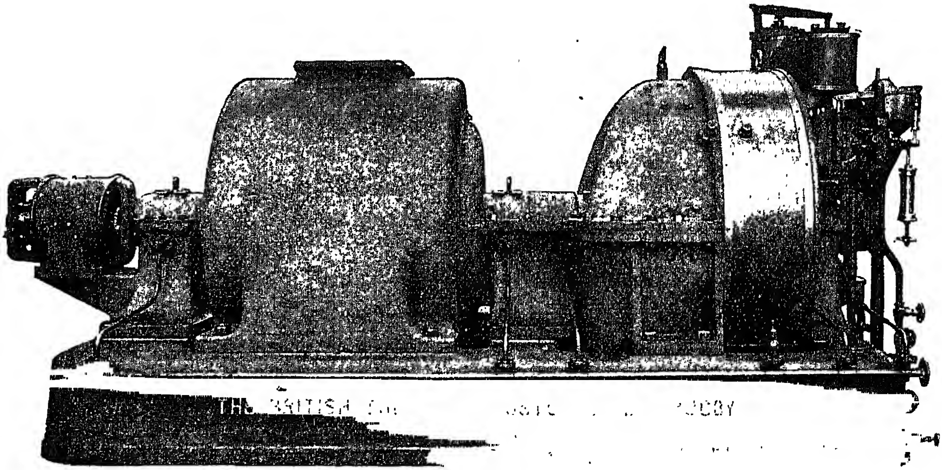


FIG. 65.

to their discs and in the balancing of each wheel. On such big circumferences the marking off has to be of the most precise kind, so as to obtain a nicety of balance.

Curtis Turbines.—The Curtis turbine is made by the General Electric Co. at Schenectady in America, and the British Thomson-Houston Co. in Great Britain. These turbines are made to run either on a vertical axis as shown in Fig. 64, or on a horizontal axis as shown in Fig. 65.

A reference to Fig. 64 shows the general construction and principle of this turbine. Steam is admitted by a number of poppet valves as shown at A, which open successively as the load increases; it is then delivered in an axial direction and

impinges on the first line of buckets B milled out of and carried on a steel disc increasing in thickness towards the hub. After passing through B the steam travels through a fixed series of guides C to a second line of buckets B_2, thence through a third series of guides D to a third line of buckets B_3. The kinetic energy only of the steam is utilized, the flow through the buckets being maintained at constant pressure. There is thus an equilibrium of pressures on both sides of the rotor-disc. The velocity of the steam, of course, decreases at each stage.

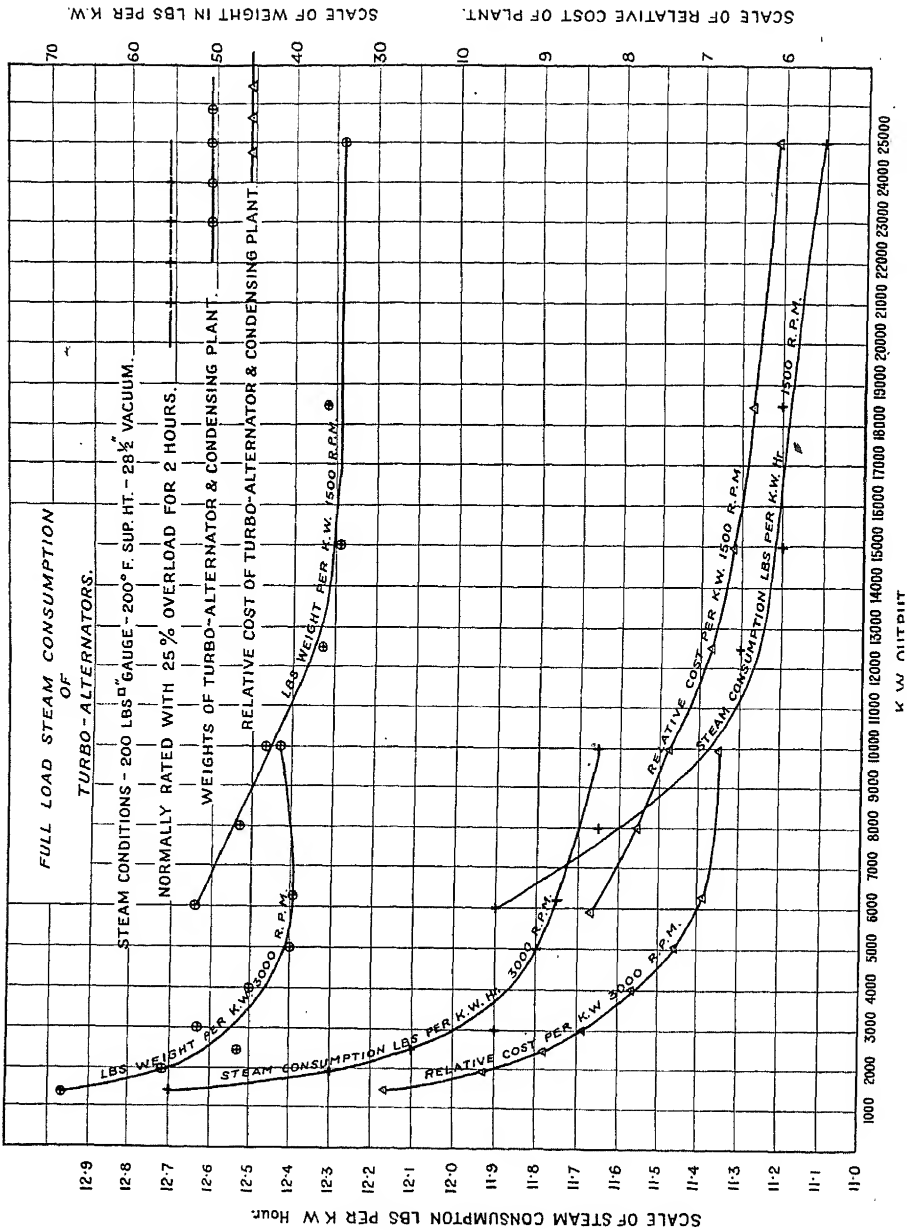
In the vertical type, a foot-step bearing E is introduced and lubricated with oil or water under a pressure of 500 lbs. per square inch. The objection to the vertical type lies in having to dismantle the generator above it in the event of any accident to the turbine discs, and also in the possible escape of steam through the high-pressure gland. The Curtis turbine normally works at a peripheral speed of 400 feet per second.

Curves are given on Fig. 66 for the steam consumption, relative costs and weights of Curtis turbines. One set of curves relates to turbo-alternators having speeds of 3000 R.P.M. and outputs ranging from 1500 K.W. to 10,000 K.W.; the other set relates to units having speeds of 1500 R.P.M. and outputs ranging from 6000 K.W. to 25,000 K.W.

The steam curves are based upon the following conditions, namely: a steam pressure of 200 lbs. per square inch (gauge), a superheat of 200° Fahr., and a vacuum of 28½ inches (95 per cent.).

With regard to relative costs, it will be seen that for sets running at 3000 R.P.M. there is not a material reduction in the cost per K.W. as between sets of 7000 K.W. and 10,000 K.W. output, the difference being under 2 per cent. For sets running at 1500 R.P.M., the cost per K.W. for sizes smaller than 10,000 K.W. rises rapidly as compared with the cost of sets of corresponding sizes running at 3000 R.P.M., the critical size at the present time being 12,000 K.W.

It may also be noted with reference to sets of 15,000 K.W. and 25,000 K.W. running at 1500 R.P.M. that while the larger unit shows a reduction of 1 per cent. only in the steam


FULL LOAD STEAM CONSUMPTION OF TURBO-ALTERNATORS.
STEAM CONDITIONS - 200 LBS □" GAUGE - 200° F. SUP. HT. - 28½" VACUUM.
NORMALLY RATED WITH 25% OVERLOAD FOR 2 HOURS.
WEIGHTS OF TURBO-ALTERNATOR & CONDENSING PLANT.
RELATIVE COST OF TURBO-ALTERNATOR & CONDENSING PLANT.
SCALE OF WEIGHT IN LBS PER K.W.
SCALE OF RELATIVE COST OF PLANT.
SCALE OF STEAM CONSUMPTION LBS PER K W Hour.
K W OUTPUT
LBS WEIGHT PER K.W. 3000 R.P.M.
LBS WEIGHT PER K.W. 1500 R.P.M.
STEAM CONSUMPTION LBS PER K.W. Hr. 3000 R.P.M.
STEAM CONSUMPTION LBS PER K.W. Hr. 1500 R.P.M.
RELATIVE COST PER K.W. 3000 R.P.M.
RELATIVE COST PER K.W. 1500 R.P.M.
70 60 50 40 30
10 9 8 7 6
1000 2000 3000 4000 5000 6000 7000 8000 9000 10000 11000 12000 13000 14000 15000 16000 17000 18000 19000 20000 21000 22000 23000 24000 25000
12·9 12·8 12·7 12·6 12·5 12·4 12·3 12·2 12·1 12·0 11·9 11·8 11·7 11·6 11·5 11·4 11·3 11·2 11·1 11·0

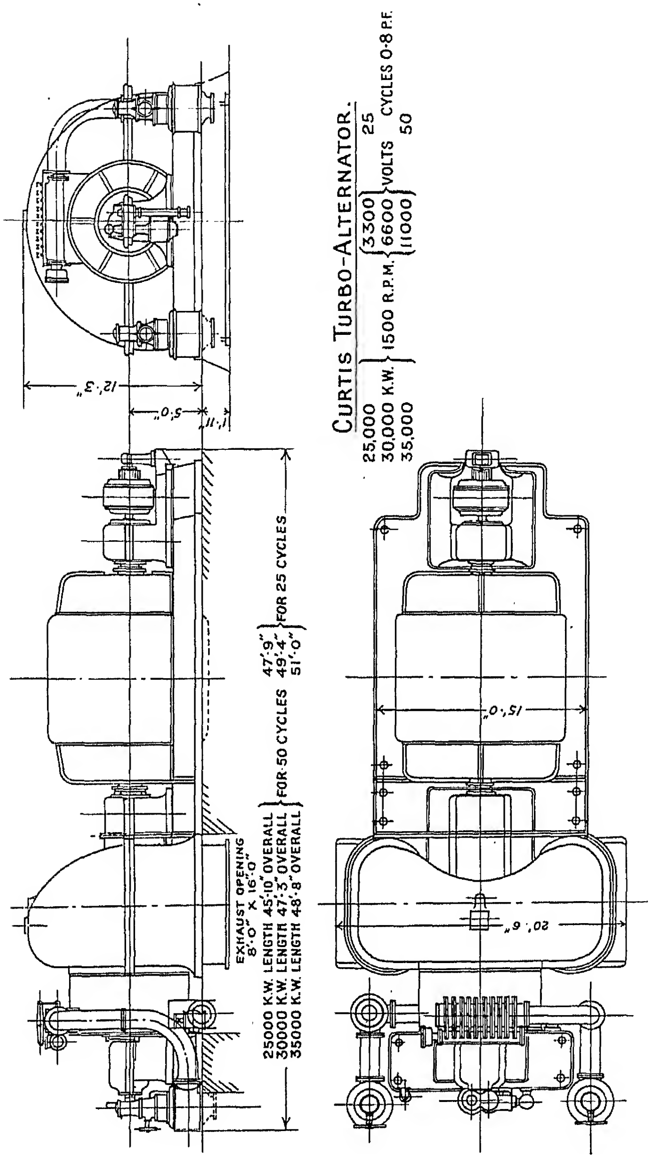


Fig. 67.

consumption per K.W.H., its cost per K.W. is 7·5 per cent. lower than that of the smaller unit.

The leading dimensions of Curtis turbo-alternator sets of

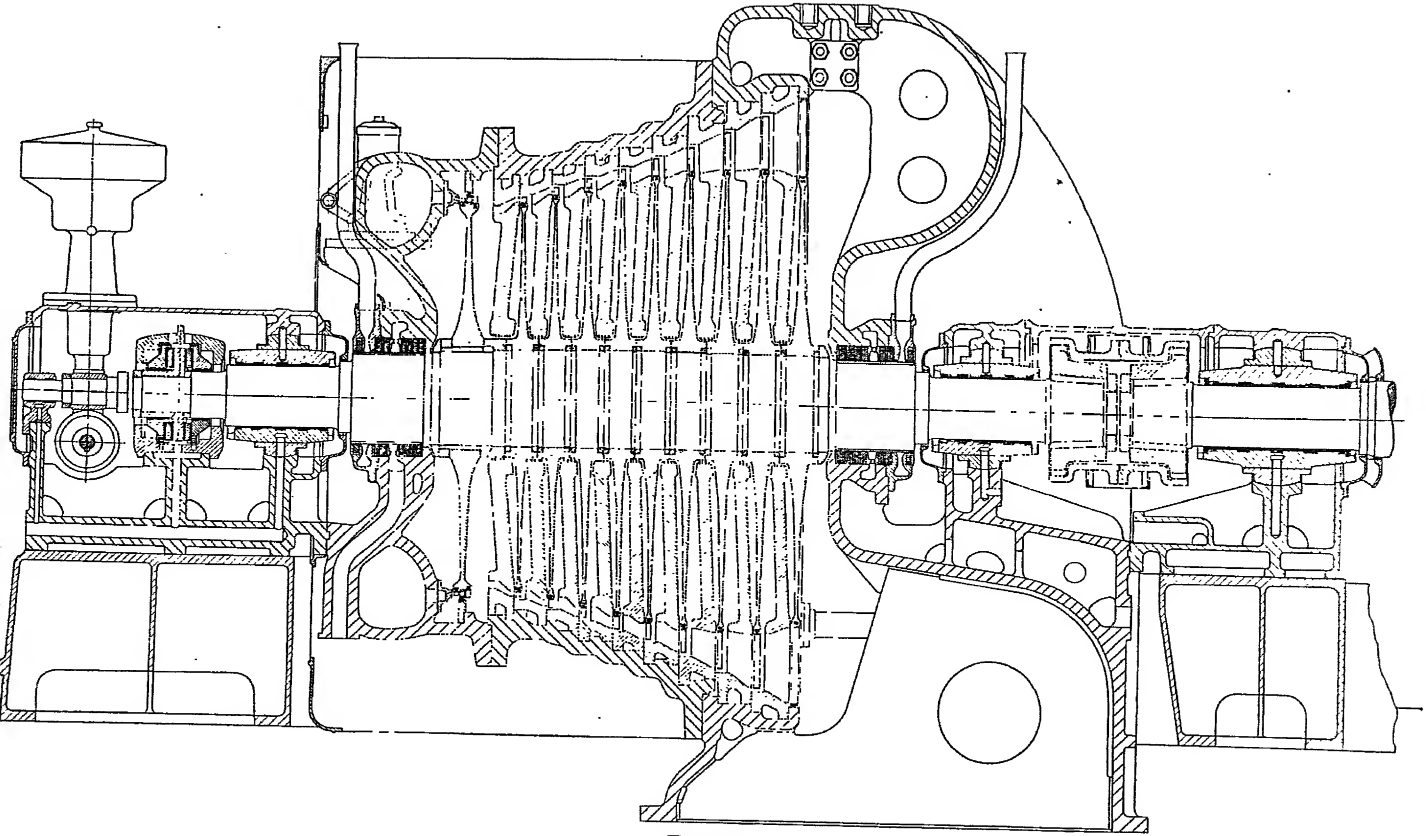


FIG. 68.

25,000 K.W., 30,000 K.W., and 35,000 K.W. capacity are shown in Fig. 67.

Zoelly Turbines.—The Zoelly turbine made by Messrs. Escher, Weiss & Co. of Zurich, and by Messrs. Howden and others in Great Britain, is another multiple stage impulse type.

The expansion of the steam from the pressure of its entry to the turbine to the vacuum conditions takes place in a series of pressure drops across the diaphragms, and the kinetic energy thus imparted to the steam is absorbed in the moving blades, the power produced being transmitted through the discs to the turbine shaft.

An English license is possessed by Messrs. The English Electric Company, who have used many of the advantageous features of Zoelly practice in the design of their standard land-service impulse machines.

Fig. 68 shows a longitudinal section through a 12,000 K.W., 1500 R.P.M. turbine as constructed by this Company. The turbine is subdivided into ten stages and it will be noted that a velocity wheel is used in the first stage in order conveniently to reduce the pressure in the turbine casing at the high pressure end.

Since the pressure of steam in all of the stages is the same on both sides of any disc, ample clearances have been allowed between the moving blades and the turbine casing, the minimum radial and axial clearances in these turbines being $\frac{1}{4}$ of an inch (6·3 mm.).

A typical diaphragm containing the fixed nozzles is shown in Fig. 69, and it will be seen that this is made in halves so that the upper portion may be removed with the cover of the turbine casing when it is desired to make an inspection of the rotor.

Overload valves are fitted so that the output of the machine can be increased, if necessary, to 25 per cent. in excess of the normal rated full load.

The following advantages are claimed for this type of machine:—

(*a*) Ample clearances between all fixed and movable parts.

(*b*) As the principle involved in the design eliminates all axial thrust, balancing pistons and the steam leakages resulting from their use are avoided.

(*c*) Owing to the low pressures and low temperatures to which the casing is exposed, the design is simplified, and the

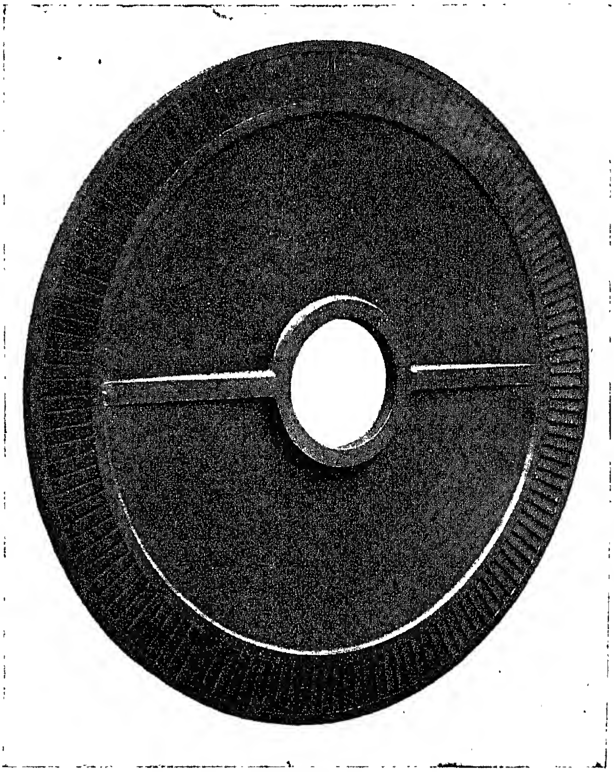


FIG. 69.

greatest advantage can be obtained from high superheat without danger from warping in the casing or moving parts.

(*d*) All bearings are automatically lubricated by a pressure system of oil supply.

(*e*) Close governing is obtained for all loads. The steam admission valves are operated from the governor through the pressure system of oil supply, and should the oil pump for any

TABLE LIII.

Approximate Particulars for Steam Turbo-Alternator Units.

(*Manufactured by the English Electric Co.*)

Output.	Speed.		Overall dimensions of turbo alternators.			Total weight of turbine and bed-plate.	Total weight of turbine alternator and condenser.	Approx. cost of turbo-alternator surface condenser and pumps. (Pre-war basis.)	Steam consumptions under stated steam conditions and efficiencies.					
	25 ∽	50 ∽	Length.	Width.	Height.				Pressure.	Super-heat.	Vacuum. (Bar. 30 ins.)	Gear efficiency.	Alternator efficiency.	Steam consumption.
K.W.	R.P.M.		ft.	ft.	ft.	tons.	tons.	£ per K.W.	lbs. per sq. in.	°F.	ins.	per cent	per cent.	lbs. per K.W. Hr.
250	5000 (geared)		17	7·5	5·75	3·5	15	12·00	180	200	28·0	97·0	92·0	18·90
500	,,		18·5	8·5	6·0	4·5	19	7·06	180	200	28·0	97·5	92·45	17·95
750	,,		20·0	11·0	7·5	12·0	29	5·50	180	200	28·0	98·0	92·9	15·78
1000	,,		21·0	11·0	8·0	13·0	33	4·60	180	200	28 0	98·0	93·2	15·10
1000		3000	21·0	7·0	5·5	20·0	40	5·60	200	200	28·5	—	93·2	13·53
2000		3000	25·0	8·25	6·0	25·0	58	3·80	200	200	28·5	—	94·1	12·90
2000	1500		24·0	10·0	6·75	50·0	80	4·90	200	200	28·5	—	93·8	13·63
3000		3000	26·5	8·75	6·0	28·5	70	3·25	200	200	28·5	—	94·6	12·63
3000	1500		25·0	11·0	7·0	60·0	105	4·00	200	200	28·5	—	94·2	13·10
5000		3000	31·5	9·75	7·5	42·5	100	2·80	250	200	28·75	—	95·0	11·85
5000	1500		33·5	12·5	8·5	70·0	140	3·15	250	200	28·75	—	94·7	11·94
7500		3000	40·5	11·5	10·0	75·0	160	2·50	250	200	28·75	—	95·0	11·40
7500	1500	1500	41·0	16·0	11·5	130·0	225	2·80	250	200	28·75	—	95·0	11·59
10000		3000	43·0	12·5	10·5	80·0	200	2·30	250	200	28·75	—	95·3	11·2
10000	1500	1500	42·5	16·5	11·5	145·0	285	2·65	250	200	28·75	—	95·3	11·26
12000		3000	45·0	13·5	10·5	85·0	230	2·10	250	200	28·75	—	95·45	11·1
12000	1500	1500	44·5	16·75	11·5	150·0	320	2·55	250	200	28·75	—	95·45	11·15
15000	1500	1500	50·0	19·5	12·5	170·0	390	2·50	300	200	29·0	—	95·7	10·38
20000	1500	1500	54·0	20·0	13·0	170·0	440	2·48	300	200	29·0	—	96·0	10·21
25000	1500	1500	56·0	20·5	13·0	200·0	550	2·48	300	200	29·0	—	96·0	10·18

TABLE LIV.

APPROXIMATE PARTICULARS FOR GEARED D.C. TURBO-GENERATOR UNITS.

(Manufactured by the English Electric Co.)

Output.	Speeds.		Overall dimensions of turbo-generator unit.			Total weight of complete unit (excluding condenser).	Total weight of complete unit (including condenser).	Approximate cost of complete unit (including condenser and pumps. (Pre-war basis.)	Steam consumptions under stated steam conditions and efficiencies.					
	Turbine.	D.C. generator (460 V.).	Length.	Width.	Height.				Pressure.	Superheat.	Vacuum (Bar. 30 ins.).	Gear efficiency.	Generator efficiency.	Steam consumption.
K.W.	R.P.M.	R.P.M.	ft.	ft.	ft.	tons.	tons.	£ per K.W.	lbs. per sq. in.	deg. F.	ins.	per cent.	per cent.	lbs. per K.W. hour.
250	5000	1000	17	7·5	5·75	9·5	15·0	11·9	180	200	28	97·0	93·0	18·70
500	5000	800	18·5	8·5	6·0	10·0	19·0	7·0	180	200	28	97·5	94·0	17·65
750	5000	700	20·0	11·0	7·5	18·0	29·0	5·5	180	200	28	98·0	94·25	15·55
1000	5000	600	21·0	11·0	8·0	20·0	33·0	4·7	180	200	28	98·0	94·25	14·90

reason fail, the steam is automatically cut off and the turbine shut down without damage.

Table No. LIII. sets out the approximate sizes, weights, steam consumptions and other particulars of standard turbo-alternators of the impulse type as manufactured by the English Electric Company. Similarly, Table No. LIV. gives the leading particulars for the same turbines coupled through gearing to D.C. generators.

Rateau Turbines.—The Rateau type is made by the Metropolitan-Vickers Electrical Co. (formerly the British Westinghouse Co.) in Great Britain and in Europe. Fig. 70 shows a general view of the construction of a 5000 K.V.A. turbine made at Manchester for the London County Council Tramways Power House.

The normal output is 5000 K.W. at power factor 0·85, and the actual output is thus 5890 K.V.A. The overload is 6250 K.W. at the same power factor. The speed is 750 R.P.M. The weight of the turbine (exclusive of alternator) is 85 tons, that of the rotor being 25 tons. The guaranteed steam consumption with steam at a pressure of 180 lbs. per square inch and a temperature of 500° Fahr., and with a vacuum of 28·5 inches was—

Rated load . . .	14·5	lbs.	per K.W.	hour
Three-quarter load .	14·75	,,	,,	,,
Half-load . . .	16·00	,,	,,	,,
Quarter-load . .	19·00	,,	,,	,,

The condenser surface adopted was 12,500 square feet, the ratio of cooling water to steam condensed being as 65 : 1.

The turbine is divided into twenty-four stages, the mean blade speed being 17,100 feet per minute, or 285 feet per second (the mean diameter of blade being 7 feet 3 inches). The wheels are steel forgings, turned and finished all over and hydraulically pressed at 20 tons on seats turned on the shaft. The shaft is 21 inches in diameter at the middle, and is thus stiff, an essential requirement in turbines of this class, since only small clearances are allowed between the shaft and the fixed diaphragms. In this turbine this difficulty is met by dovetailing a keeper

ring, made in halves, to the diaphragm, the convex surface of which surrounding the shaft is lined with serrated anti-friction

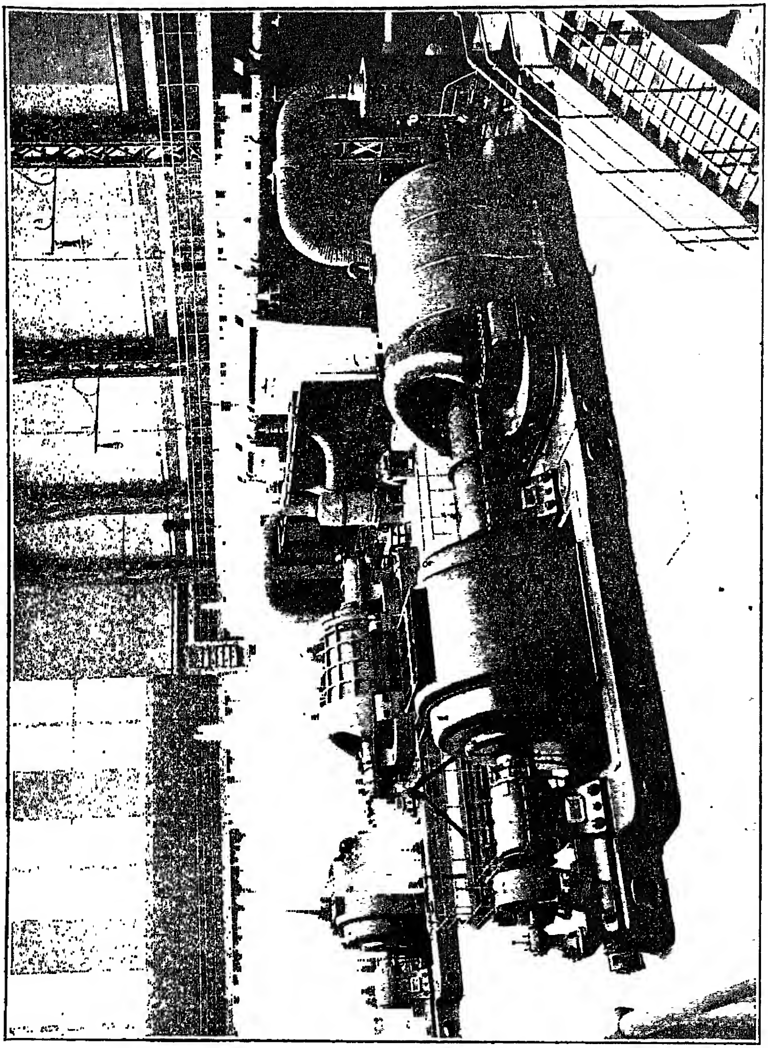


Fig. 70.

metal, scraped to an easy fit on the shaft. The blades are milled out from solid 5 per cent. nickel bars, and their accuracy of machining has been carefully worked out. The guide blade

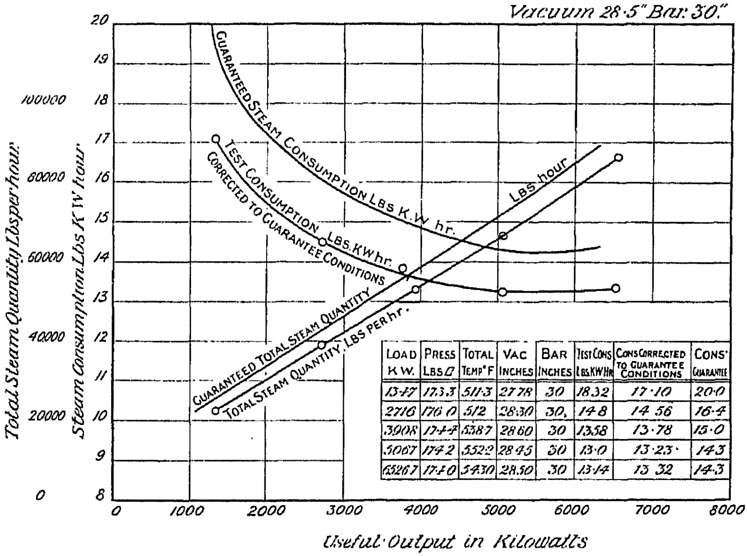
groups are arranged in a helical form, so that the steam may follow a natural path due to its velocity.

This turbine is an impulse type having a series of wheels fixed on a shaft and increasing in diameter with the various stages of expansion. The guide blades are fixed into steel division walls or diaphragms. The pressure is the same on both sides of any wheel, so that the axial thrust is very small.

Rateau turbines generally are designed to work with a steam

5000 K W High Pressure Turbine, 1500 R.P.M.

Guarantee Conditions:-Steam Press 175 lbs. □"g Total Temperature 527°F.
Vacuum 28·5" Bar: 30."



Load K.W.	Press Lbs □	Total Temp°F	Vac Inches	Bar Inches	Test Cons Lbs KW Hr	Cons Corrected to Guarantee Conditions	Cons' Guarantee
1347	173.3	511·3	27 78	30	18 32	17·10	20·0
2716	176 0	512	28·30	30.	14·8	14 56	16·4
3908	174·4	538·7	28 60	30	13·58	13·78	15·0
5067	174 2	552·2	28 45	30	13·0	13·23	14·3
6526·7	174·0	543·0	28.50	30	13·14	13 32	14·3

Fig. 71.

pressure of 180 lbs. at the stop valve, a total steam temperature of 500° Fahr., and a vacuum equivalent to 95 per cent. of the barometric pressure, as above stated in the case of the L.C.C. machine. The speed being only 750 R.P.M., of course involves more wheels of a larger diameter than would be the case with sets running at 1000 or 1500 R.P.M. In turbines of this class running at 1500 R.P.M., there are only half the number of wheels, and these are necessarily of much less diameter. The steam consumption of low-speed turbines is also necessarily

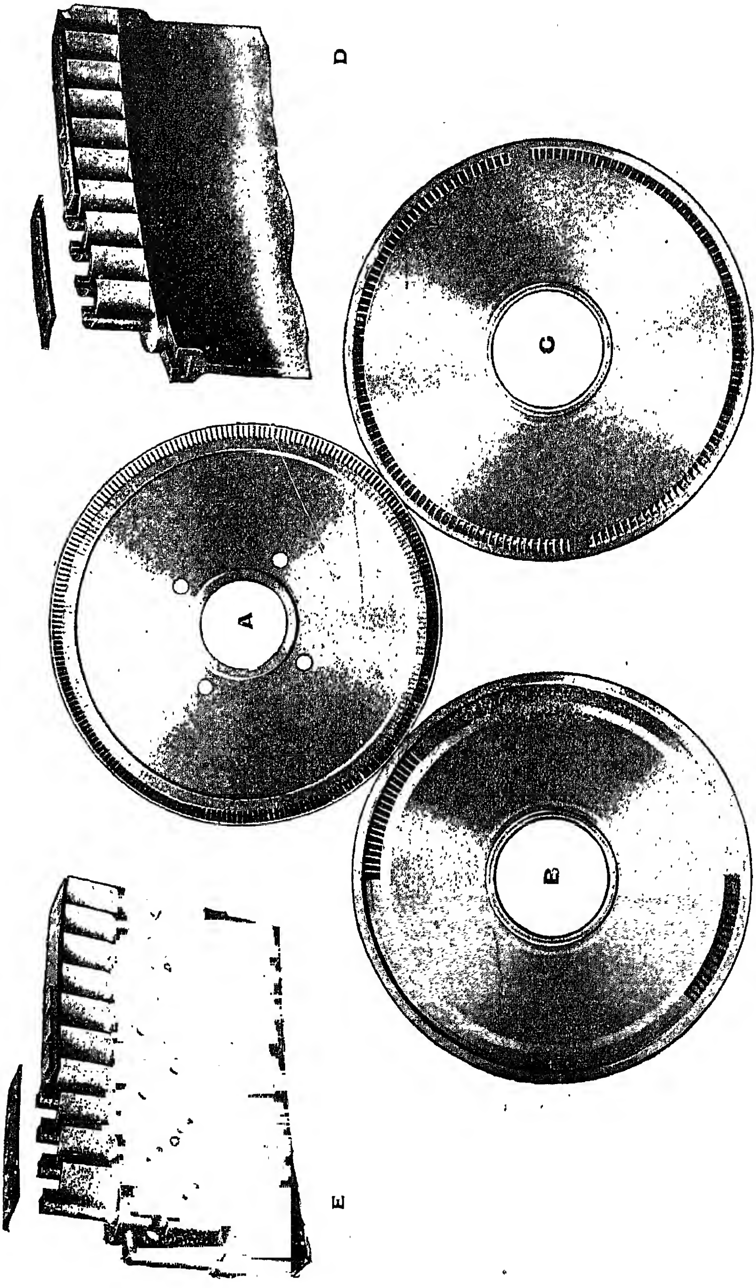


FIG. 72.

greater than that of high-speed sets, and the capital cost is also greater.

Fig. 71 shows the guaranteed and the test figures of steam consumption for a 5000 K.W. Westinghouse Rateau turbine running at 1500 R.P.M.

The construction of the impulse wheels of this turbine is beautifully worked out, and is described below with reference to Figs. 72 and 73, the former figure also showing a group of fixed diaphragms.

The guide blades fixed on the circumferences of the diaphragms increase from stage to stage, as shown at B and C, Fig. 72, until they occupy the entire circumference, as shown at A. The diaphragms are fixed in circumferential grooves machined in the interior of the turbine casing, and are made of cast iron, divided along the horizontal diameter; special provision being made to prevent leakage along the shaft from stage to stage. The guide blades are of nickel steel, specially machined to the correct theoretical angle.

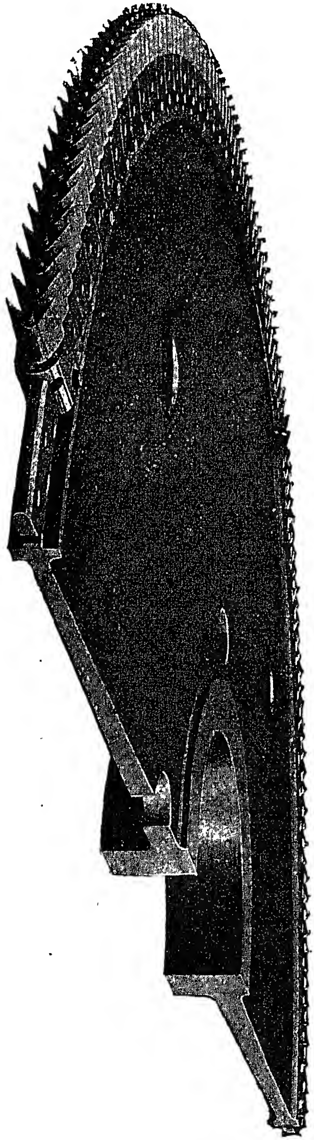


Fig. 73.

The impulse wheels are very thoroughly made, being forged from a high-class steel in one piece with the hub, very carefully turned, and so proportioned to the stresses that the factor of safety is never less than five. The blades are fixed either as

shown at D, or as shown at E. A steel shrouding band is riveted solidly to each blade, and as the steam pressure, as in all impulse turbines, is the same at both sides of the wheel, a radial clearance of 0·2 or 0·3 inch can be given between the casing and outer face of the shrouding. Each blade is very accurately machined to standard jig and checked with the greatest precision, and can either be slipped over the end of the wheel in a forked manner, as shown at E, or into a T-shaped groove, as shown at D. In the former case each blade is riveted, the discs or blades having been previously accurately drilled in special machines, the whole wheel being then accurately turned up and balanced. Fig. 73 is a view of a completed half-wheel.

Leading particulars of Rateau turbines made by the Metropolitan-Vickers Electrical Co. of Manchester in sizes ranging from 500 K.W. to 35,000 K.W. are set out in Table No. LV.

TABLE LV.

LEADING PARTICULARS OF RATEAU TURBINES.

(Manufactured by the Metropolitan-Vickers Electrical Company.)

Output.	Speed.	Combined set.				Weight.	
		Approx. overall length.	Width.	Height from engine-room floor.	Depth of basement from engine-room floor.	With surface condenser.	Without condenser.
K.W.	R.P.M.	ft. ins.	ft. ins.	ft. ins.	ft. ins.	tons.	tons.
500	3000	18 2	6 9	5 11	12 6*	25	20
1,000	3000	19 9	7 0	5 11	13 0*	35	28
1,500	3000	23 3	8 0	6 8	13 3*	45	37
2,000	3000	22 10	8 3	7 1	14 0*	55	45
3,000	3000	24 4	8 3	7 1	15 3*	58	46
5,000	3000	30 0	11 9	5 10	14 3	91	78
6,000	3000	32 0	12 0	5 10	14 9	97	83
8,000	3000	34 9	12 3	6 2	16 3	123	103
10,000	3000	37 3	12 3	6 2	17 0	136	112
12,000	3000	40 0	12 6	6 8	18 6	148	122
15,000	1500	45 3	18 3	10 6	22 0	176	146
20,000	1500	46 6	18 3	10 6	23 6	260	215
25,000	1500	49 0	18 6	10 6	24 6	300	246
30,000	1500	52 3	18 6	10 6	25 0	—	—
35,000	1500	53 6	18 6	10 6	26 0	—	—

* Dimensions are inclusive of sluice valve.

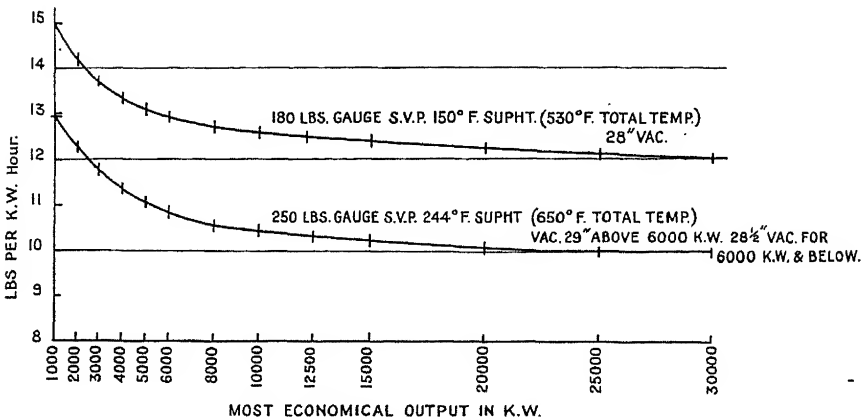
Reaction Turbines.—The reaction type turbine, i.e. that in which the pressure at the entrance to the rotating wheel is greater than the pressure at the exit side, is the well-known Parsons turbine. This type is a multiple stage, and the clearances have to be very small in order to keep down leakages and to induce economy in steam consumption. The blades are made from drawn bronze placed in grooves on the wheel, or in the casing, and caulked in position by small pieces of the same metal. The ends of the blades are usually fitted with a shrouding ring. Only very minute clearances are permissible, e.g. 35 mils. radially and 64 mils. horizontally at the high-pressure stage in a 5000 K.W. set. The stuffing boxes are formed by labyrinth glands made up of a number of rings with alternate fine and coarse clearances. Balancing pistons have, of course, to be adopted to neutralise the end thrust on the turbine due to the differences in the pressure on successive faces of each wheel. The shafts are necessarily long in these turbines when of large powers, so that with the fine clearances necessary to good economy in steam consumption very great care has to be exercised in designing the proportions of the shaft, in balancing the rotor accurately, and in starting up the turbine so as not to get unequal expansions in the rotor.

A micrometer test taken on a reaction turbine when cold, and during every succeeding 10 seconds while the turbine was being warmed up, from which a curve was drawn, showed the maximum distortion of the shaft from the centre to be 27 mils. The slow warming up causes the rotor to take up different positions in respect of its axis, and if the rotor be started up while distorted, due to a difference of temperature between the top and bottom of the casing, stripped blades and a want of running balance will be the probable results. The best way to start up a reaction-type turbine is to close the emergency valve, and to get a fair pressure behind it, and then to lift the valve suddenly so that a puff of steam is taken into the turbine which is thus started up at once. The turbine should be run dead slow for several minutes so that the rise in temperature may be evenly distributed, after which it can be run up to load. The

superheat has to be carefully regulated so as to preserve a uniform temperature during any run.

Curves are given in Fig. 74 for the steam consumption of Parsons' turbines having outputs ranging from 1000 K.W. to 30,000 K.W. under the following two sets of conditions namely:—

(*a*) A steam pressure of 180 lbs. per square inch at the stop valve, a superheat of 150° Fahr. (total steam temperature 530° Fahr.), and a vacuum of 28 inches (93·3 per cent.); and



REACTION TURBINES.

Curves showing the steam consumption of turbo-alternators with given steam conditions for plants of 1000 to 30,000 K.W. capacity. Designed for periodicity 50 ∼ per sec. Speed 1500 R.P.M. for plants above 10,000 K.W.; speed 3000 R.P.M. for plants of 10,000 K.W. and below; single cylinder for plants of 8000 K.W. and below; tandem cylinder with 2 flow low-pressure turbine for plants above 8000 K.W.

FIG. 74.

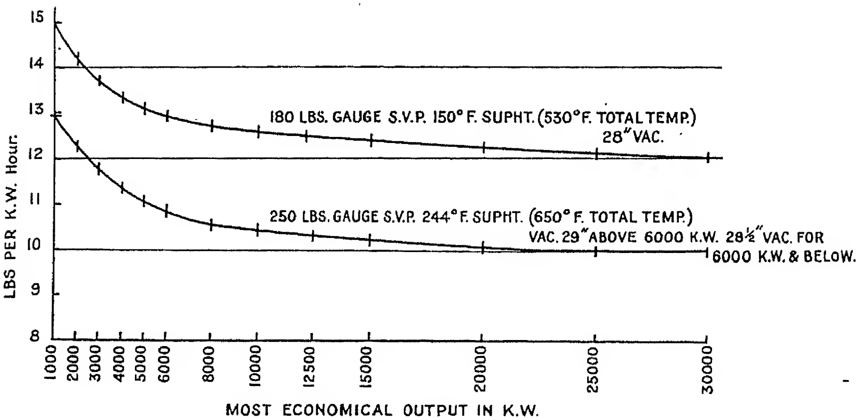
(*b*) A steam pressure of 250 lbs. per square inch at the stop valve, a superheat of 244° Fahr. (total steam temperature 650° Fahr.), and a vacuum of 28½ inches (95 per cent.) for sizes up to 6000 K.W. capacity and of 29 inches (96·6 per cent.) for sizes above 6000 K.W.

It may be noted that as between the two sets of physical conditions, there is a saving with a 25,000 K.W. unit of 17·5 per cent. on steam consumption at the higher pressure and superheat. From the lower curve in Fig. 74 it will also be seen that

superheat has to be carefully regulated so as to preserve a uniform temperature during any run.

Curves are given in Fig. 74 for the steam consumption of Parsons' turbines having outputs ranging from 1000 K.W. to 30,000 K.W. under the following two sets of conditions namely:—

(a) A steam pressure of 180 lbs. per square inch at the stop valve, a superheat of 150° Fahr. (total steam temperature 530° Fahr.), and a vacuum of 28 inches (93·3 per cent.); and



REACTION TURBINES.

Curves showing the steam consumption of turbo-alternators with given steam conditions for plants of 1000 to 30,000 K.W. capacity. Designed for periodicity 50 ~ per sec. Speed 1500 R.P.M. for plants above 10,000 K.W.; speed 3000 R.P.M. for plants of 10,000 K.W. and below; single cylinder for plants of 8000 K.W. and below; tandem cylinder with 2 flow low-pressure turbine for plants above 8000 K.W.

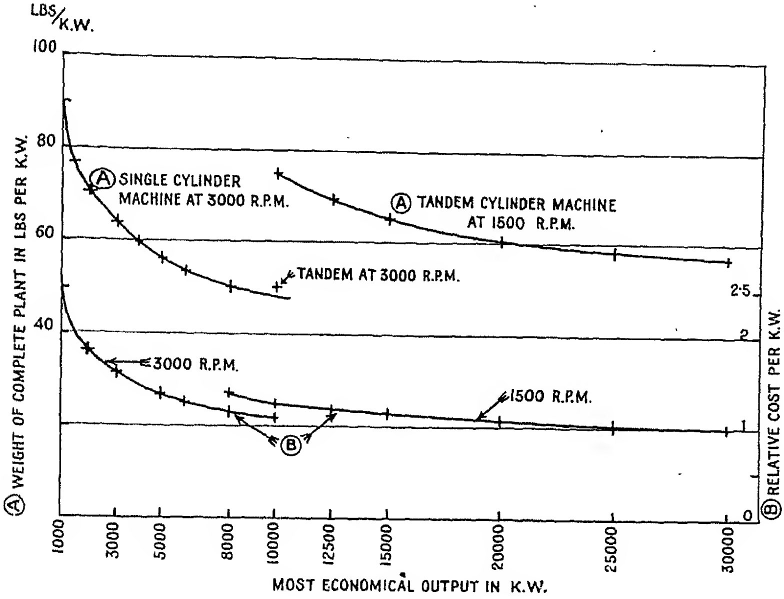
FIG. 74.

(b) A steam pressure of 250 lbs. per square inch at the stop valve, a superheat of 244° Fahr. (total steam temperature 650° Fahr.), and a vacuum of 28½ inches (95 per cent.) for sizes up to 6000 K.W. capacity and of 29 inches (96·6 per cent.) for sizes above 6000 K.W.

It may be noted that as between the two sets of physical conditions, there is a saving with a 25,000 K.W. unit of 17·5 per cent. on steam consumption at the higher pressure and superheat. From the lower curve in Fig. 74 it will also be seen that

as between units of 15,000 K.W. and 30,000 K.W. operating under the same conditions, the saving with the larger unit is only 3 per cent.

The effects of superheat and of vacuum on the performance of Parsons' turbines are also shown by the following results. In the case of experiments made by Professor G. Stoney, F.R.S., at Elberfeld, there was an economy of 1 per cent. in steam con-



Reaction Turbines.

Curves (A) show the weight per K.W. of 50 ∼ turbo-alternator plants from 1000 to 30,000 K.W. economical load. This weight includes turbine alternator, condenser, and bedplate.

Curves (B) show the relative cost per K.W. for the same plants taking that of a 30,000 K.W. plant as unity.

Fig. 75.

sumption for every increase of 6·8° C. (12·2° F.) in superheat. In other tests made at Cheltenham, a reduction of the back pressure from 0·46 lb. to 0·25 lb. (absolute) gave a saving of 8·95 per cent. in steam consumption, the theoretical gain being 12·4 per cent.; on still further decreasing the back pressure to 0·22 lb., a further gain of 4·65 per cent. was obtained.

The two curves given in Fig. 75 show (*a*) the weight per

K.W. of 50 cycle turbo-alternator sets, inclusive of turbine, alternator, condenser, and bedplate, and (*b*) the relative costs per K.W. They show very clearly the effect of stepping from 3000 R.P.M. to 1500 R.P.M., and also from a single cylinder to a tandem machine. Here again, as in the curves given on Fig. 66 for impulse turbines, the critical size at which the speed is stepped down from 3000 R.P.M. to 1500 R.P.M. is about 12,000 K.W. With regard to relative costs, it will be seen that the cost per K.W. of a 30,000 K.W. set is about 13 per cent. less than that of a 15,000 K.W. unit.

Much larger sets than those indicated in Figs. 74 and 75 are now in actual operation; for example, the three-element 60,000 K.W. set constructed by the Westinghouse Co. at East Pittsburgh, for the 74th Street Power House of the Interborough Rapid Transit Co., New York, and illustrated in Fig. 76.

This set is designed on the cross-compound principle and consists of three elements of the reaction type, namely, one high-pressure turbine and two low-pressure turbines, each element being coupled direct to its own generator. Each of the three turbines develops a rated load of 20,000 K.W. (25 cycles, 3-phase, 11,000 volts), the whole unit having a continuous rating of 60,000 K.W. at a power factor of 0·85, and being capable of developing loads of 70,000 K.W. for short periods. The set is designed to operate with steam at a gauge pressure of 205 lbs. superheated 150° Fahr. (total temperature 540° Fahr.), and to exhaust at a vacuum of 29 inches (96·6 per cent.). The high-pressure turbine contains 50 rows of blades, runs at a speed of 1500 R.P.M., and exhausts into the low-pressure turbines, each of which has 44 rows of blades, and also runs at a speed of 1500 R.P.M.

Under normal conditions, the low-pressure elements do not receive any high-pressure steam direct, but are automatically connected to the high-pressure supply if the high-pressure turbine is shut down. If the two low-pressure turbines are shut down from any cause not affecting the high-pressure element, the latter continues in operation and exhausts into the atmosphere. The main steam piping consists of two 18-inch high-pressure lines. The set is arranged with valves and pipe connections so that all

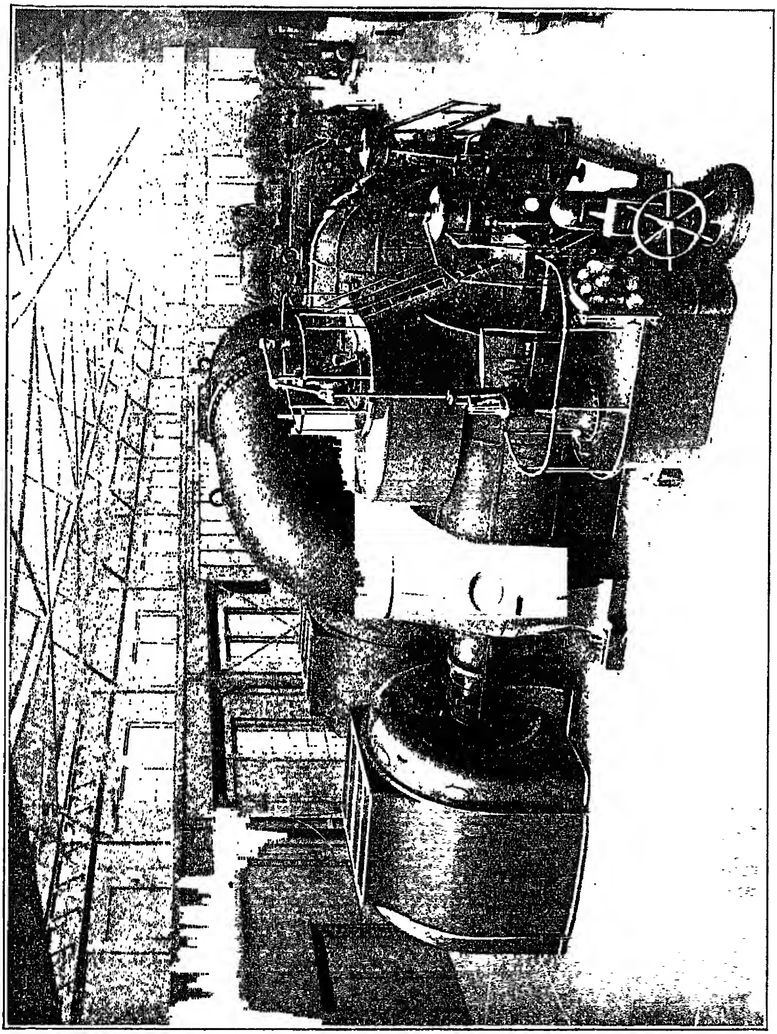


FIG. 76.—60,000 K.W. cross-compound turbo-alternator set.

three elements can work together as one complete unit, or so as to permit of the operation of any individual turbine element or of a combination of the high-pressure element and either of the low-pressure elements.

The following steam consumptions for various loads apply when the set is exhausting at a vacuum of 96·6 per cent :—

Load : 60,000 K.W.	Steam : 10·75 lbs. per K.W.H.
,, 50,000 ,,	,, 10·55 ,, ,, ,,
,, 40,000 ,,	,, 10·70 ,, ,, ,,
,, 30,000 ,,	,, 11·05 ,, ,, ,,

The condensing equipments are of the Westinghouse-Le-Blanc type. There are two condensers connected to each low-pressure turbine, and the total area of cooling surface is 100,000 square feet, equivalent to 1·66 square feet per K.W. full load rating. There are four circulating pumps, one of which is spare; four rotary air pumps, and four rotary condensate pumps. The total shipping weight is 1,200 tons, and the heaviest piece to be handled by the crane is 70 tons. The floor space occupied is 2600 square feet (52 feet in length by 50 feet in width), equivalent to 0·045 square foot per K.W. rated load, and the height from basement level is 19 feet 3 inches.

When operating the high-pressure turbine and only one low-pressure element, the continuous rating is 30,000 K.W. with a steam consumption of 12·1 lbs. per K.W.H. under approximately the above-named conditions of superheat and vacuum; and when operating one low-pressure turbine only as an independent unit supplied with high-pressure steam, the continuous rating is 20,000 K.W. (or 23,500 K.W. for two hours) with a steam consumption of 14·25 lbs. per K.W.H.

The atmospheric relief system is provided with relief valves connected with the condensers, and one back pressure valve set to operate at 66 lbs., all of these discharging through a common 48-inch uptake.

There is a system of electrical control with a signal equipment operated at 125 volts D.C. This apparatus enables any one of the three machines to be cut out of service by operating the automatic stops, the two remaining sets continuing in service. The low-pressure turbine pressure is about 35 lbs., and

when an emergency shut-down is necessary the automatic valve referred to breaks the vacuum. The control and governor system has been satisfactorily tested under continuous working conditions for a considerable time.

Brush-Ljungström Turbine.—The Brush-Ljungström turbine, manufactured in Great Britain by the Brush Electrical Engineering Company of Loughborough, is being extensively used and has many exceptional qualities. This turbine is of the reaction type, and owing to there being two rotors revolving in opposite directions, thus giving a relative speed equal to double the running speed, a high efficiency is obtained with minimum centrifugal stresses.

Concentric sets of blade rings are mounted upon the opposing faces of two rotor discs, the rings of one disc lying between those of the other, as shown in the cross-sectional illustration in Fig. 77. The blades are set in opposite directions so that the flow of the steam is reversed alternately by the rings attached to the two discs. Steam is admitted to the central core of the blade system and then expands outwards radially. The outer casing of the turbine is thus in contact with low-pressure steam and at the low temperature equivalent to the exhaust pressure. Any lagging of the turbine casing is thus unnecessary, and a low engine-room temperature is also ensured.

Though the turbine is of the reaction type in which very small clearances are necessary to proper efficiency and low steam consumption, the risk of stripped blades in the Ljungström type is almost negligible, because not only is the diameter small in comparison with that of other types owing to the double rotation, but the extreme light weight of the turbine rotors allows the whole of the material in them to respond quickly to variations of temperature. The carefully thought-out details of construction greatly reduce the tendency of the clearances to alter under any condition of load. Thin nickel strips are caulked into the stiffening rings of the blade rings and should contact take place there is no stripping but the nickel strip would be slightly worn down. The whole turbine wheel system is very compact and accessible and can be easily lifted bodily from the casing by removing the top half-casing, as shown in Fig. 78.

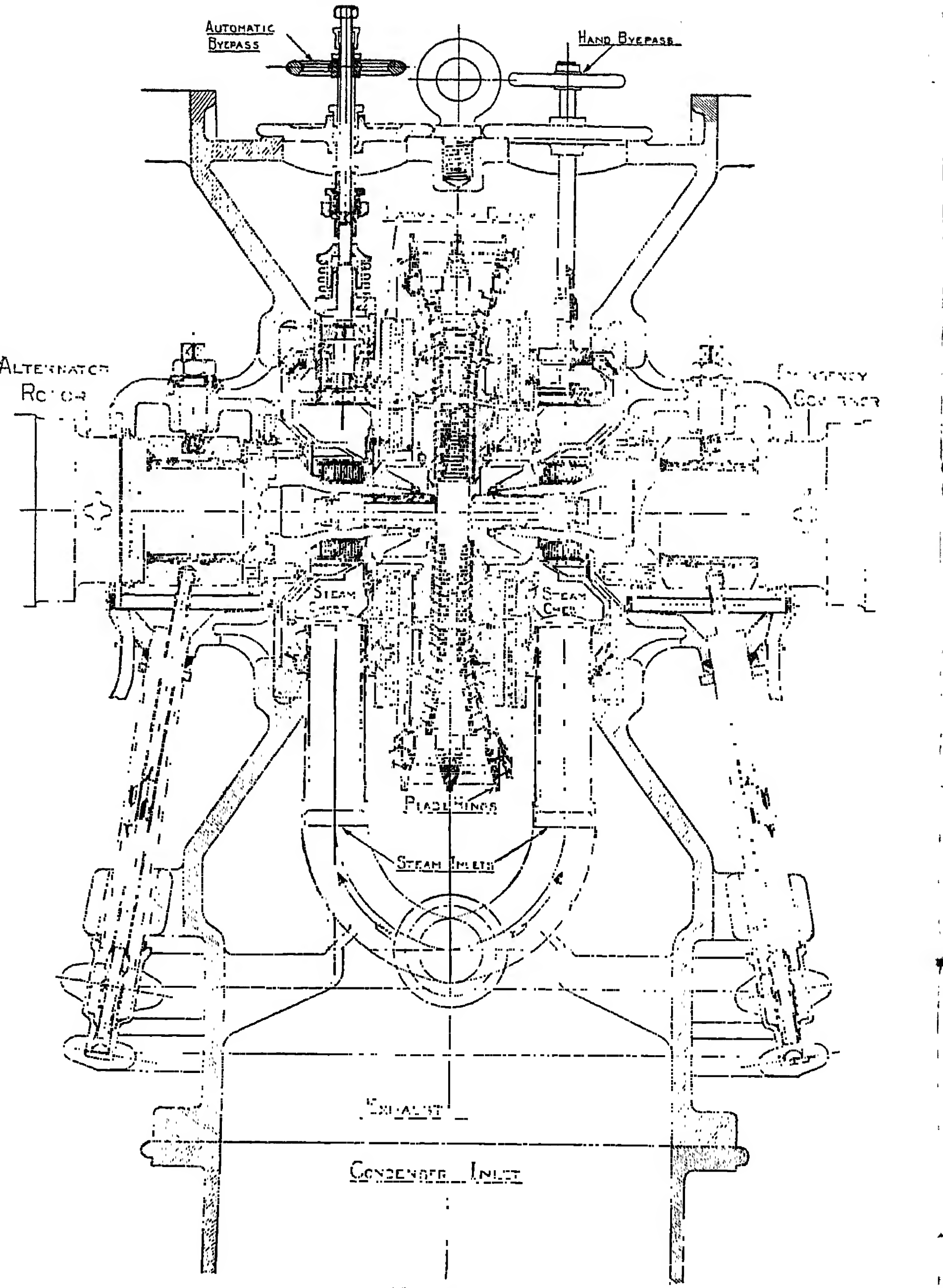

Automatic
Byepass
Hand Byepass
Steam
Steam
Steam Inlets
Condenser Inlet

Fig. 77.

The standardised sizes, all of which run at 3000 R.P.M., are 1000, 1500, 3000, and 5000 K.W., but larger sizes are contemplated up to 15,000 K.W. and beyond.

Particulars of Brush-Ljungström sets are given in Table No. LVI.

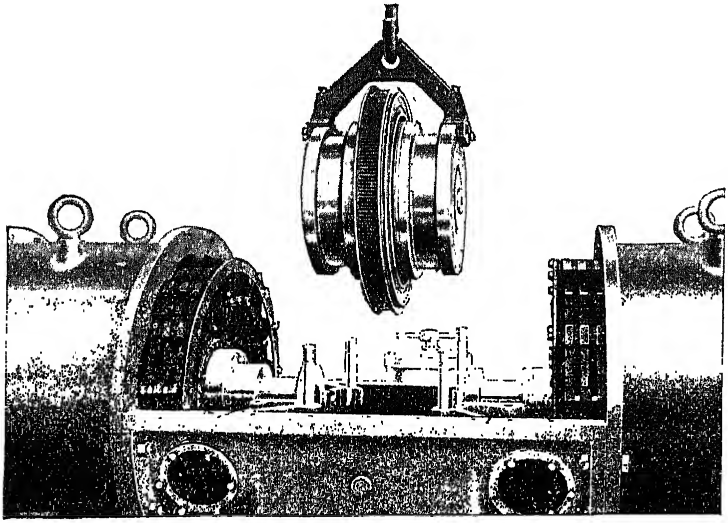


FIG. 78.

TABLE LVI.

PARTICULARS OF BRUSH-LJUNGSTRÖM TURBO-ALTERNATORS.

Size.	Speed.	[1] Total weight.	Length.	Maximum width.	Floor space per K.W.	Approximate price per K.W. (pre-war).
K.W.	R.P.M.	tons.	ft.	ft.	sq. ft.	£
1000	3000	30	21	13·5	0·283	6·00
1500	3000	35	23·5	16	0·250	4·80
3000	3000	60	28	17·25	0·161	3·33
5000	3000	75	30	19·25	0·116	2·88

[1] NOTE.—Including surface condenser, as up to 5000 K.W. the turbine, alternator, and condensing plant form one interdependent unit, the turbo-alternator being mounted direct through an exhaust trunk on the condenser which is designed specially for the purpose.

High efficiencies and low steam consumption are claimed for this type of plant, and despite the two alternators per set (which of course revolve in opposite directions) the cost of the complete set is low owing to its simplicity of design and low weight per kilowatt. In installing sets up to 5000 K.W., no engine-room floor is necessary as the whole plant is borne by the condensers from the basement floor. Only a light operating platform is therefore required to give access to the turbine for valve operating and inspection or dismantling. The removed parts can be lowered from the crane direct on to the basement floor. All this tends to reduce the size and cost of the engine-room, and the turbine itself is specially adaptable for overseas stations on account of its compactness and low shipping weight.

Combined Impulse and Reaction Turbines: "Disc and Drum Type".—A compromise can be made by introducing a combination of the impulse and reaction types, as in the Belliss and Morcom turbine, and this principle has been adopted by many other makers. There is a velocity wheel, which reduces the admission pressure through nozzles to a figure only a little above the atmospheric pressure; the energy is further utilized by expanding the steam through a series of reaction stages to the final exhaust pressure. In this way large ranges of temperature are removed from the turbine casing and the consequent stresses due to expansion and contraction are reduced to a minimum.

The weak point in reaction turbines of the Parsons type is the high-pressure blading, where the clearances are very small. As the leakage at this point must be kept down, there is greater risk of fouling, and consequent stripping of the blades with a possible further trouble of shaft distortion. At the low-pressure end the clearance is only a small proportion of the blade area, and thus the clearance can be made large enough to prevent fouling without appreciable leakage losses.

The dangers just referred to are eliminated in a turbine known as the Impulse "disc and drum" type made by Messrs. Willans & Robinson—now the English Electric Company—and up to the end of 1914 several hundreds of these machines had been put into successful operation.

The turbine rotor consisted of a two velocity stage impulse

wheel directly fixed to a drum carrying the reaction blading. The first expansion of steam from the pressure at the turbine stop valve to a pressure corresponding approximately with that of the atmosphere was carried out in fixed nozzles and the kinetic energy so gained was absorbed in the blading of the impulse wheel, the remainder of the expansion to vacuum conditions being dealt with in the reaction elements.

It was possible by this means to obtain comparatively large clearances throughout the turbine, and the danger of fouling and stripping was greatly reduced. The pressure of the steam in the turbine casing never being greater than that of the atmosphere, the temperature could be kept low and dangers from distortion were practically eliminated.

The distance between bearings in a turbine of this type is considerably reduced. The impulse wheel is steam balanced, and the low-pressure blading balanced by a piston at the exhaust end, so that the exhaust end gland has atmospheric pressure on both sides, and the tendency of steam to leak outwards or air to leak inwards is eliminated.

Mixed Pressure Turbines.—A mixed pressure turbine has four characteristics in that it can be operated with :—

(*a*) Exhaust steam only.

(*b*) High-pressure steam only.

(*c*) High-pressure and exhaust steam simultaneously.

(*d*) High-pressure steam non-condensing.

These changes can be effected automatically without interference with the speed.

In the Westinghouse Rateau type, Fig. 79, which may be taken as an example of this class of turbine, both the high and low-pressure steam chests are contained in one casting. The valves are so linked up that if there is sufficient exhaust steam available to drive the turbine, the H.P. steam is entirely cut off. Should the exhaust steam fall below the required quantity, then the governor automatically opens the H.P. valve sufficiently to keep the turbine up to its load. If the exhaust steam supply fail altogether, the L.P. valve is shut, and the whole load carried on H.P. steam. This latter change prevents any back pressure being formed in the exhaust steam-pipe feeding into the turbine,

so that no condensed steam can be forced back into the reciprocating engines providing this exhaust steam supply.

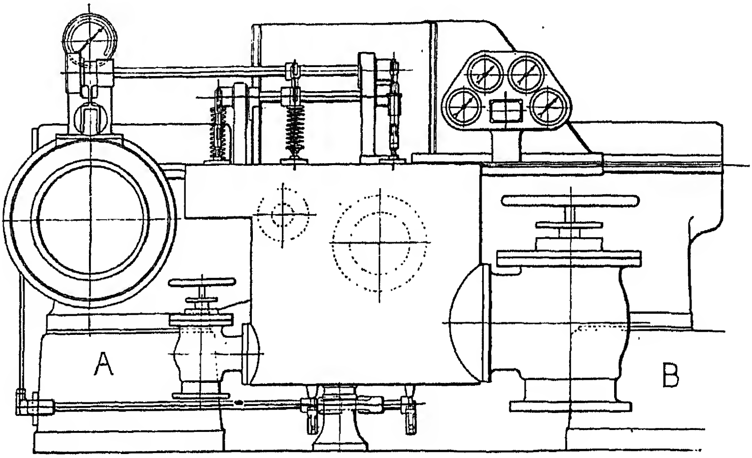


Fig. 79.

Fig. 80 shows a longitudinal section through a mixed pressure turbine of this type.

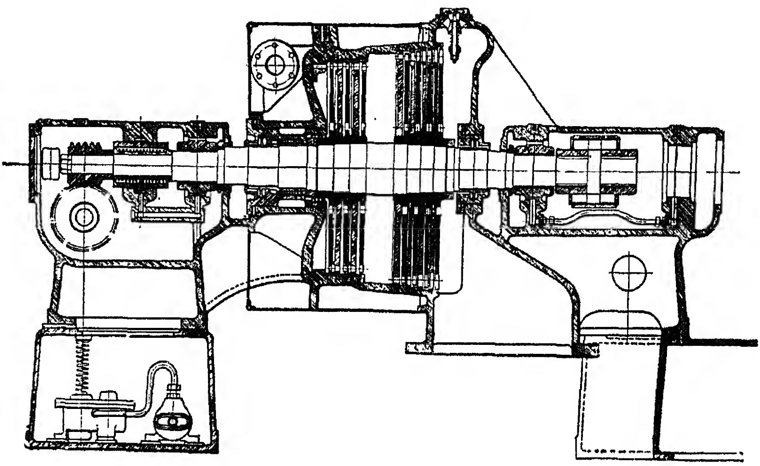


Fig. 80.

These turbines are especially useful where power is required for an electric power house auxiliary in works employing engines working intermittently, such as reversing rolling mills,

steam winders or blowing engines, and offer an alternative to a simple exhaust-steam type with regenerator as described later.

Fig. 81 gives the H. and L.P. steam consumption of a 700 K.W. Rateau mixed-pressure turbine running at a speed of 2500 R.P.M., the guaranteed conditions being a H.P. admission of 120 lbs. per square inch, and a vacuum of 27¾ inches (Bar. 30 in.), and a L.P. of 16 lbs. per square inch, with a vacuum of 27½ inches. The figure shows not only the guaranteed

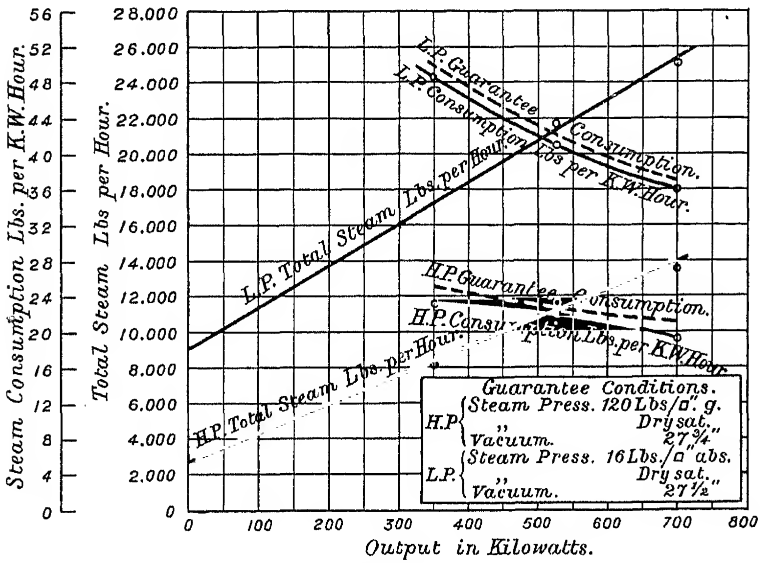


Fig. 81.

consumption, but also the official figures obtained per unit generated.

Exhaust Turbines.—As a means to economy, and as a compromise between the large capital outlay on new modern plant on the one hand, and the writing off of capital expenditure and the heavier running costs of existing reciprocating plant on the other, exhaust turbines may be installed to run in conjunction with existing engines. Low-pressure turbines are fixed and inserted between the exhaust of the engines and the condenser, whereby a more useful plant with a greatly increased revenue-

earning capacity is obtained without any additional capital outlay on boilers and buildings, and merely at the cost of the turbine unit plus some costs which may have to be incurred in improving the condensing plant. Nor is there any increase in the steam raised, the effective result being simply the addition of another stage or expansion to the engine. The thermal efficiency, taking the reciprocating engine and the turbine as one unit, is also raised considerably.

The capital cost per K.W. is largely reduced, i.e. the revenue-earning capacity of the plant is increased with only a small increment of total cost, and the running cost of fuel is enormously reduced. Therefore the commercial efficiency of the plant is very greatly increased through the influence of both of these factors.

Fig. 82 shows a combination steam consumption diagram for two 750 K.W. Belliss and Morcom reciprocating engines, and one 800-1000 K.W. exhaust turbine. The steam pressure is 180 lbs. per square inch and the total temperature 500° Fahr., and the curves show the resultant pounds of steam per K.W. hour for three values of the vacuum. The pressure between the engines and the turbine is 15 lbs. absolute, and the back pressure 2 lbs., 1½ lbs., or 1 lb., equivalent to a 26-, 27-, or 28-inch vacuum respectively (Bar. at 30 inches). Table No. LVII. gives the steam consumption at full load.

TABLE LVII.

Reciprocating Engine and Exhaust Turbine Combination.

Items.	Engines.	Turbine.			Combination.		
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
Back pressure (lbs. absolute)	—	2	1½	1	2	1½	1
Consumption per K.W. hour	23·8	45·2	39·8	35·2	15·6	14·9	14·2
Total steam per hour	17,850	—	35,700	—	—	35,700	—
Kilowatts output	1,500	790	895	1014	2230	2,395	2514

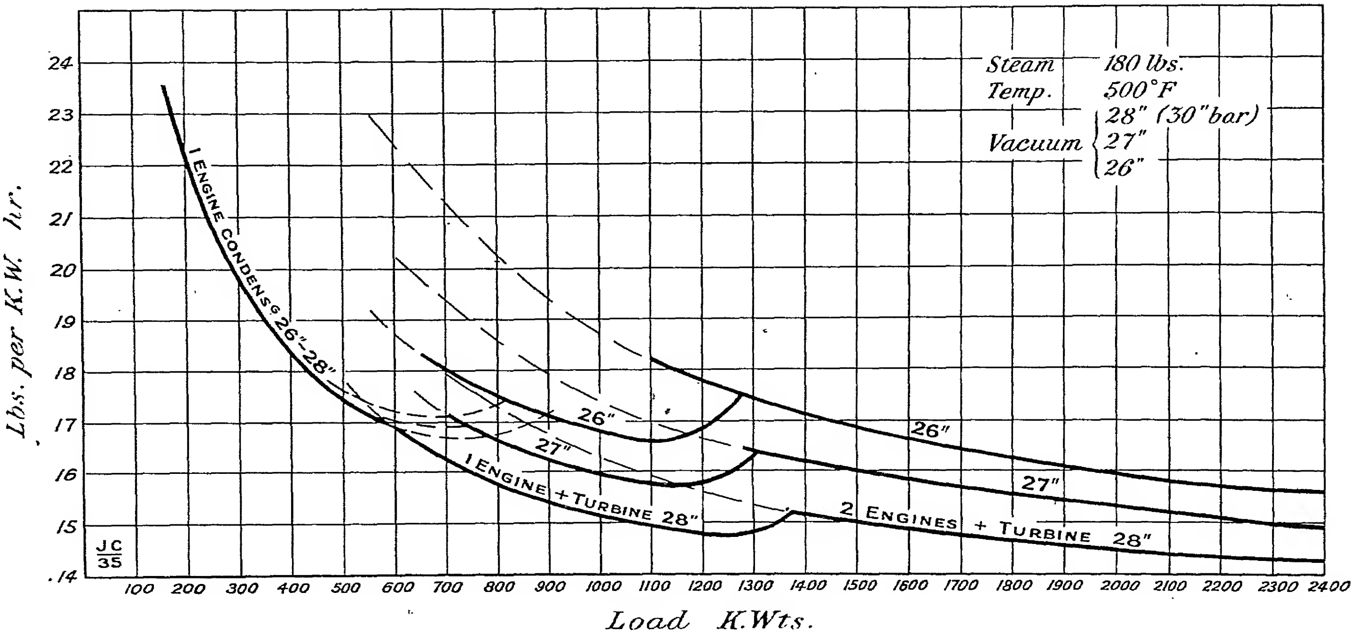
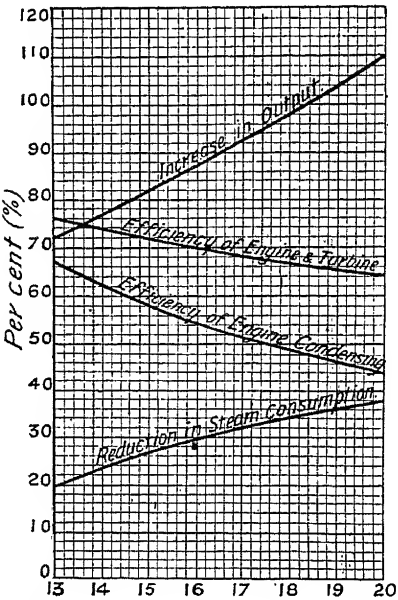

Steam 180 lbs.
Temp. 500°F
Vacuum 28" (30" bar) 27" 26"
1 Engine Condens^g 26"-28"
26"
27"
1 Engine + Turbine 28"
2 Engines + Turbine 28"
JC/35
Lbs. per K.W. hr.
24
23
22
21
20
19
18
17
16
15
14
100 200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400 1500 1600 1700 1800 1900 2000 2100 2200 2300 2400
Load K.Wts.

Fig. 82.

Fig. 83 was prepared from Table No. LVIII. taken from a very able paper read by Mr. W. N. Bailey before the Manchester Association of Engineers. The figure shows the increase in output and the reduction in steam consumption per resultant K.W. hour for an engine working with saturated steam at 160 lbs. and combined with a turbine exhausting into a 26-inch vacuum.



Steam Consumption of Engine Condensing.
160 lbs. saturated steam 26" Vac.
FIG. 83.

It will be seen that the addition of the turbine increases the total output by 72 per cent., or, in other words, the reciprocating engine contributes 58 per cent., and the exhaust turbine 42 per cent. of the total output; whilst the steam consumption per unit generated is reduced at full load by 20 per cent.

TABLE LVIII.

TABLE FROM WHICH CURVES IN FIG. 83 ARE DERIVED.

1000 I.H.P. triple expansion engine: exhaust pressure range (absolute) from 175 lbs. to 15 lbs. for engine, and from 15 lbs. to 1 lb. for turbine.

A	B	C	D	E	F	H	J	K	L	M
13	67·0	80·0	17·8	10·0	1721	10·35	20·0	76·0	721	72·1
14	62·3	75·3	18·8	9·0	1770	10·64	24·0	73·7	770	77·0
15	58·2	71·2	20·0	8·4	1822	11·0	26·6	71·4	822	82·2
16	54·6	67·6	21·0	7·5	1874	11·2	30·0	70·0	874	87·4
17	51·4	64·4	22·1	7·0	1923	11·5	32·3	68·3	923	92·3
18	48·5	61·5	23·1	6·5	1971	11·73	34·7	66·8	971	97·1
19	46·0	59·0	25·0	6·1	2055	12·18	36·0	64·5	1055	105·5
20	43·7	56·7	26·0	5·7	2100	12·4	38·0	63·3	1100	110·0

The columns in the table set out the following data:—

Col. A = Steam consumption of engine per I.H.P.
,, B = Efficiency of engine, condensing.
,, C = ,, ,, non-condensing (assumed).
,, D = Steam consumption, non-condensing.
,, E = Per cent. moisture.
,, F = Total I.H.P. output of engine and turbine.
,, H = Steam consumption of engine and turbine.
,, J = Per cent. reduction in steam consumption.
,, K = Efficiency of engine and turbine.
,, L = Equivalent I.H.P. from turbine = $\frac{\text{K.W.} \times 1{\cdot}34}{0{\cdot}92 \times 0{\cdot}9}$ taking $\frac{\text{I.H.P.}}{\text{B.H.P}} = 0{\cdot}9$.
,, M = Per cent. increase in output due to turbine.

Designers are very seriously asked to consider such a combination when they are dealing with extensions of existing plant. It will often be found the best compromise to improve the economy and increase the output of an existing power house by the addition of exhaust turbines, rather than to build a modern power house and adopt all the latest appliances, or to continue to run an uneconomical station. A function of the engineer is to prevent waste, and to get the best out of the materials he may have ready to hand. Exhaust turbines in many cases will be found of great utility. They would not, of course, be used in any power house of modern design, since the designer would obviously proceed to the greatest economy at once by the adoption of high-pressure turbines.

There are many existing installations, such as isolated atmospheric exhausting electrical power houses, and reversible or non-reversible mill engines where, owing to the low ratio of compounding of the cylinders or the high steam consumption, considerable economy could be gained by fixing exhaust turbines in series between the reciprocating plants and an added condensing plant. Greater economy can be obtained by these means than by the addition of a condensing plant alone. Not only is there a greater heat economy, but the commercial economy is greater, after making due allowance for the capital cost of the added turbine. At the Poensgen Steelworks, Dusseldorf, several engines were connected to a common condenser plant with a resultant economy of 15 per cent. By the

addition of a regenerator-turbine system this economy was raised to 40 per cent.

A reference to Fig. 84 will show that the heat energy represented by the shaded area between the admission pressure of 140 lbs. and the atmospheric line is practically equal to that represented by the shaded area between the atmospheric line and the practical vacuum which may be obtained in modern condensing plants without undue cost in running the condenser auxiliaries.

The entropy diagram shown in Fig. 85 makes this clearer still, and shows the energy which is utilizable in exhaust turbines.

An engineer has not only to consider the design of new power houses, but it is also his duty to make the most of the existing materials. Thus in large works of a special nature there will be many cases where it will be better practice to utilize the otherwise waste products in an electrical power house than to provide new steam-raising plant. The subject of Power House Design includes such applications, and the Author would be failing in duty and in thoroughness not to make a full reference to them.

An excellent and typical example of the application of an exhaust turbine was given

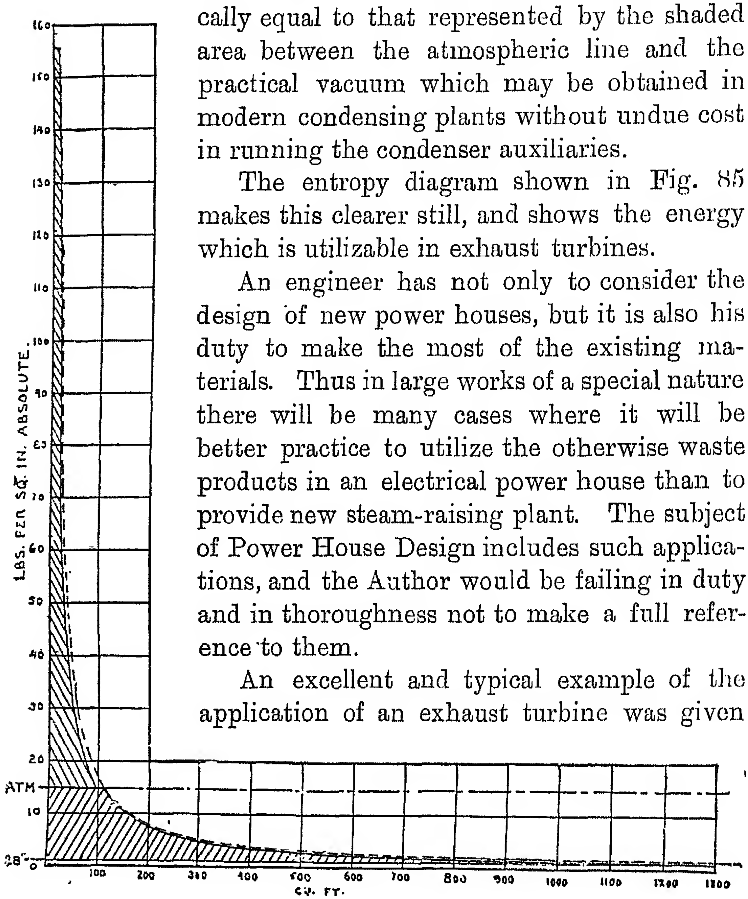


FIG. 84.

in an admirable paper read before the American Institute of Electrical Engineers in 1907 by H. H. Wait, to whom the Author is indebted for several practical results which he has used in this work.

The plant described by Wait was installed at the Wisconsin Steel Company's Works at South Chicago, the primary engine being a 42″ × 60″ double cylinder reversible rolling mill, indicating 1010 maximum H.P., and averaging 820 H.P. per hour, thus being practically idle for 20 per cent. of the rolling, with several stops lasting variously from a few seconds to several minutes.

The exhaust steam first passes to a receiver which equalizes the puffs from the exhaust—which are at high pressure, since live steam is taken practically throughout the stroke—thence into a regenerator from which the turbine is supplied, and so to a condenser.

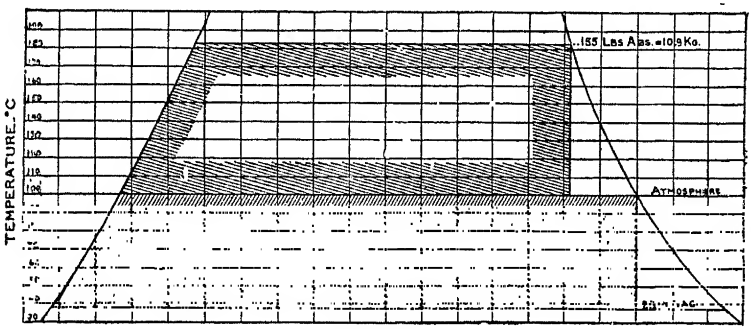


FIG. 85.

The regenerator is of a special design, as shown in Fig. 86, and so constructed that the turbine is supplied with steam at practically atmospheric pressure. A number of perforated pipes are immersed in the water contained in the regenerator so that the exhaust steam delivered to them is sprayed through the mass of water. Some of the steam is thus condensed and gives up its heat to the water. The steam entering at about atmospheric pressure has, of course, a temperature of about 212° Fahr., and tends to raise the water to that temperature. When the primary engine stops and the exhaust supply ceases, there is a large volume of water at or about 212° Fahr. A steady load on the exhaust turbo-generator drawing its steam supply from the regenerator, reduces the pressure in the latter, so that saturated

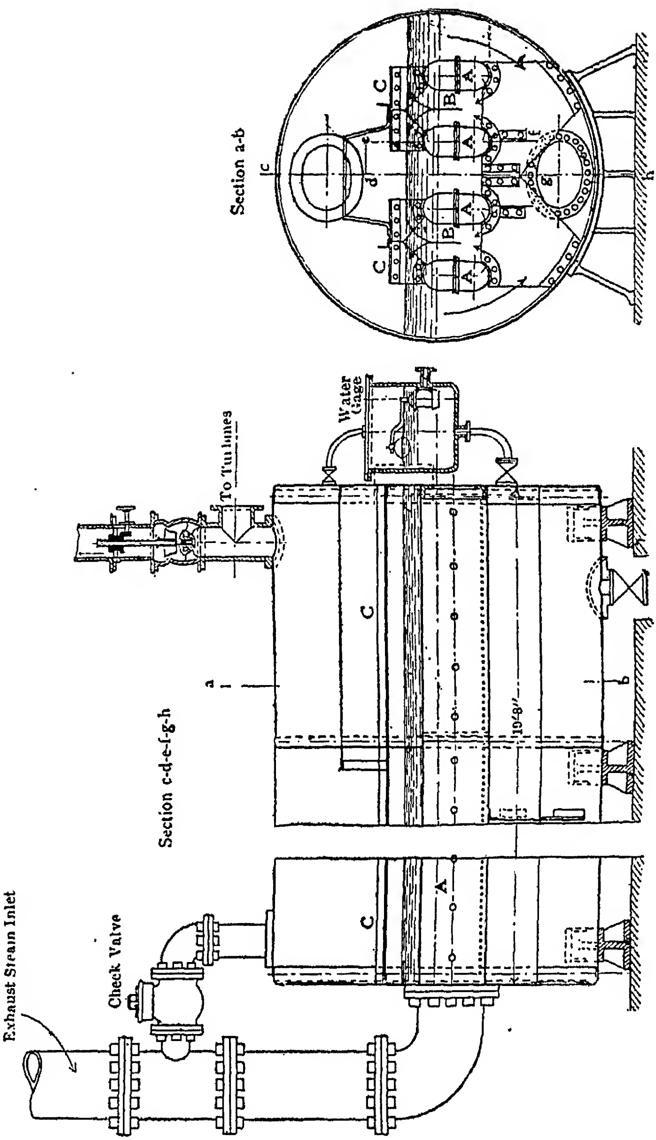


FIG. 86.

steam is given off by the water then below atmospheric pressure. When the primary engine again starts, a further supply of exhaust steam comes over to the regenerator, again raising the

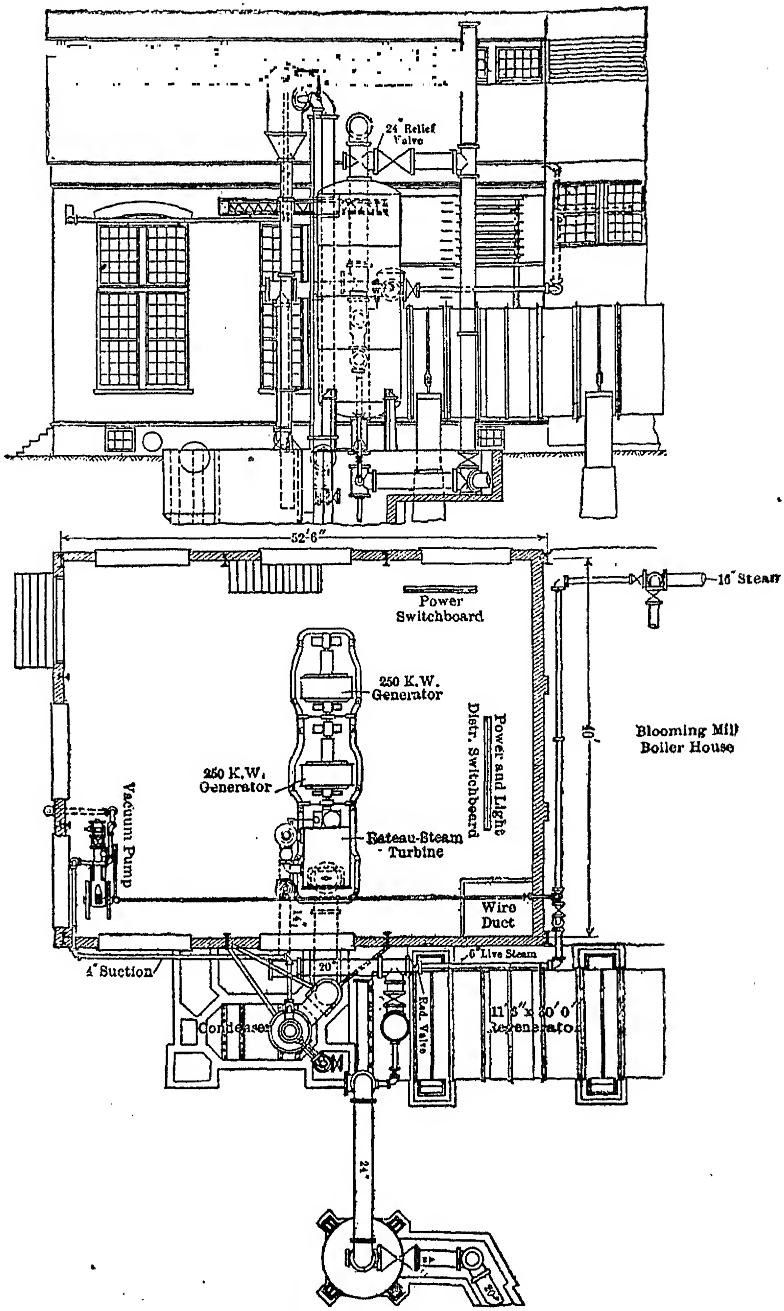

24" Relief Valve
52'-6"
16" Steam
Power Switchboard
250 K.W. Generator
250 K.W. Generator
Power and Light Distr. Switchboard
40'
Blooming Mill Boiler House
Vacuum Pump
Rateau-Steam Turbine
Wire Duct
6" Live Steam
4" Suction
20"
Condenser
Red. Valve
24"

Fig. 87.

water temperature. The regenerator is, in fact, a heat accumulator. Should the primary engine be stopped too long and beyond the storage capability of the regenerator, then live steam is admitted through a reducing valve to make up the deficiency. On the other hand, should the load on the turbine be too small for the time being to use up all the exhaust steam from the primary engine, then an atmospheric valve is operated and the excess steam escapes. Any excess of water accumulating in the regenerator is drained off by a special trap.

Figs. 87 and 88 show the general arrangement of the Rateau regenerator turbine equipment, and Fig. 89 a sectional elevation of a Westinghouse Rateau exhaust turbine.

In this instance the turbine drives two dynamos, each of 250 K.W. output, and the results of four tests were as follows:—

TABLE LIX.

	I.	II.	III.	IV.
Average barometer (ins.)	29·6	29·6	29·2	29·2
,, vacuum at turbine (ins.)	25·3	26·6	26·9	26·4
,, kilowatts output	266	366	489	591
,, steam per K.W. hour (lbs.)	73·3	55·2	45·2	49·5

The addition of condensing plant only would have reduced the steam consumption of the reversing mills from 64 lbs. per average H.P. per hour to 38 lbs., according to the very best published results from other similar plants. By the addition of the turbine, the total pounds of steam averaged over both the primary mill engine and the turbine were only 22·1 per H.P. per hour, after allowing for the further condenser auxiliaries.

There are many places where supplementary power house equipment of the above character could be utilized with great economy, not only in steel rolling mills, with blast furnace blowing engines, and in some of the older reciprocating engine electrical power houses, but also in textile mills, collieries and mines, paper mills, and other large factories. The turbo-generators could be utilized not only for the lighting of the works and for crane driving, but also to supply motors to drive the numerous auxiliary machines required in such works.

The steam velocities in low-pressure turbines can be reduced to a low value by subdivision of the expansions into many stages.

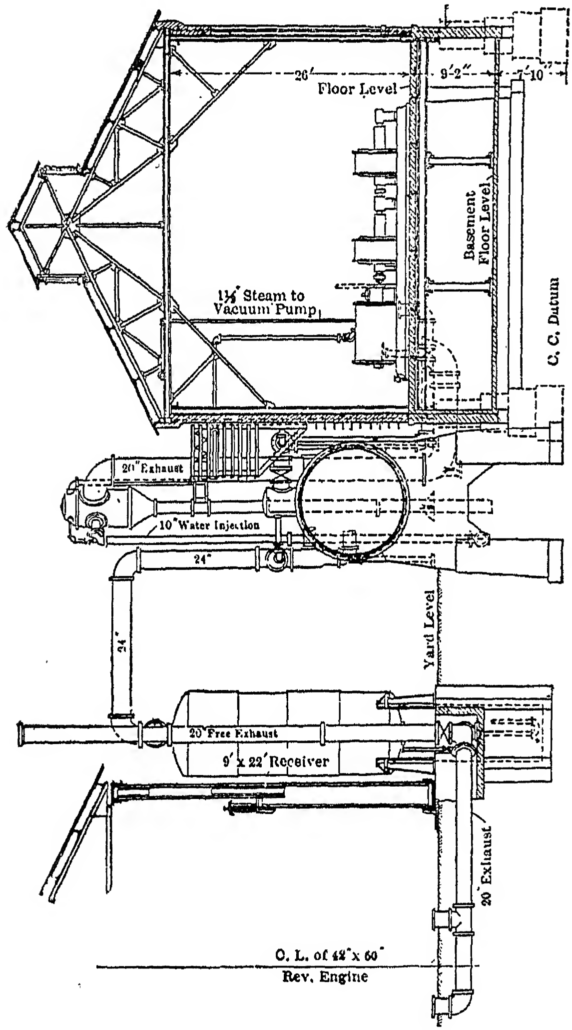


FIG. 88.

This reduces the attrition on the edges of the blades or buckets, and a case is authenticated where, after five years' almost continuous use, the blades still showed the tool marks. This is a

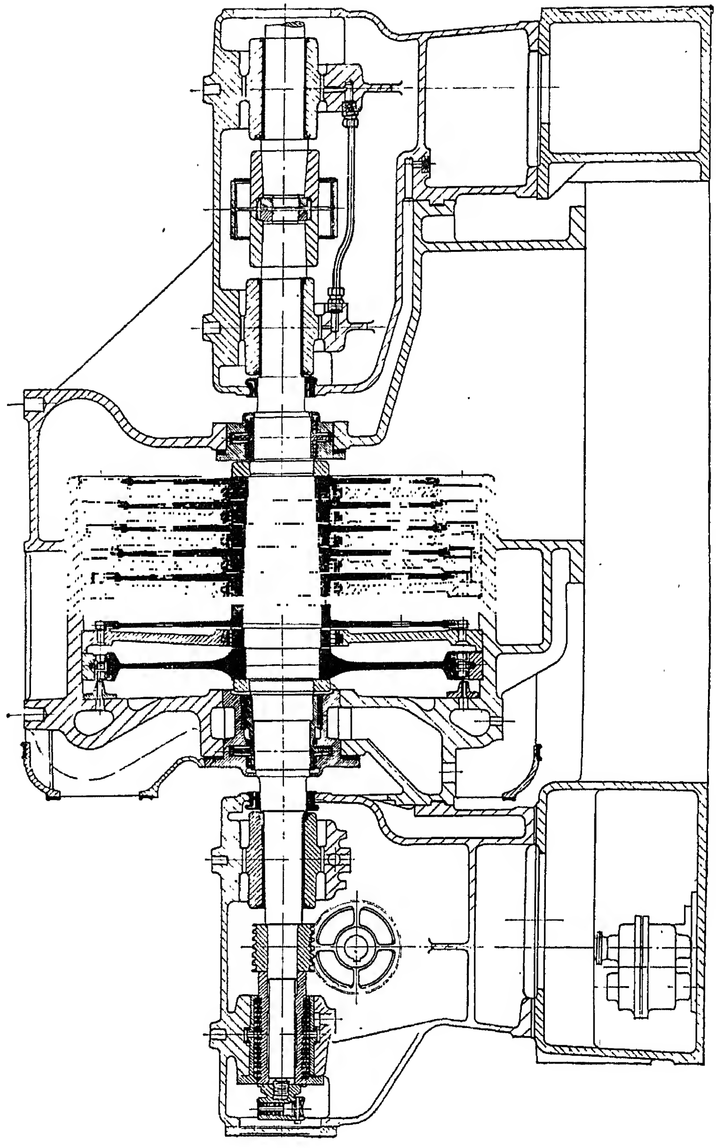


FIG. 89.

very important consideration with low-pressure turbines when the steam is saturated or even surcharged with moisture.

Combined Power and Heating Installations.—Reference may be made at this stage to another class of problem affording the designer an opportunity of effecting economies in capital outlay and working costs, namely, the provision of power plant for a works or factory requiring large quantities of steam for manufacturing purposes such as heating, boiling, etc. In such cases, a substantial advantage is often to be gained by resorting to back-pressure working and utilizing the exhaust steam from reciprocating engines or turbines for meeting the requirements of the factory. The steam is raised at a pressure higher than that necessary for the manufacturing operations and after being passed through the engine or turbine, which functions as a reducing valve, is exhausted into the heating or other system at a pressure sufficient to give the desired temperature.

As compared with a factory utilizing high-pressure boilers for the power plant and low-pressure boilers for other steam requirements, an installation designed for back-pressure working shows a saving in boilers, pipe-work and space, and a reduction in the total consumption of fuel, the extent of these savings depending, of course, upon the nature of the requirements to be met.

The type and arrangement of power plant best suited to the needs of a particular factory can only be determined after a careful study of the conditions. In cases where the power requirements are large, where the steam needed for the manufacturing operations must be quite free from oil or grease, or where flexibility regarding the pressure and temperature of the exhaust steam is of importance, it may prove preferable or even necessary to instal turbines. On the other hand, where the power requirements are small or moderate but it is at the same time necessary to develop the maximum possible power from a given quantity of steam, then the use of reciprocating engines may offer the best solution. In other cases where the maximum demands for power and for exhaust steam do not coincide, a combination consisting of a back-pressure unit and a condensing unit may prove the most suitable.

The following Table, No. LX., given by Messrs. Belliss and Morcom, shows the approximate B.H.P. obtainable with back-pressure reciprocating engines for various inlet and exhaust pressures.

TABLE LX.

POWER OUTPUT OF BACK-PRESSURE RECIPROCATING ENGINES.

Approximate B.H.P. per 1000 lbs. of dry steam per hour at specified inlet and exhaust pressures.												
Inlet pressures ; lbs. gauge.	Exhaust pressures ; lbs. gauge.											
	Atmospheric.	5	10	20	30	40	50	60	70	80	100	125
40	20·0	—	—	—	—	—	—	—	—	—	—	—
50	23·5	20·0	—	—	—	—	—	—	—	—	—	—
60	26·0	22·5	19·0	—	—	—	—	—	—	—	—	—
80	32·0	27·5	24·0	18·5	—	—	—	—	—	—	—	—
100	38·0	33·0	28·0	22·5	17·5	13·0	—	—	—	—	—	—
125	42·0	38·0	33·0	26·0	21·5	17·5	14·0	—	—	—	—	—
150	44·0	41·0	37·0	31·0	25·0	21·0	17·0	14·5	12·5	—	—	—
175	46·0	43·0	40·0	34·0	28·0	23·5	20·5	18·0	15·0	13·0	—	—
200	47·0	44·5	42·0	36·5	32·0	27·5	23·5	20·5	18·0	15·5	12·0	—
225	48·0	45·5	43·0	38·0	34·0	30·5	26·5	22·5	20·5	18·0	14·0	10·5
250	49·0	46·5	44·0	39·0	36·0	32·5	28·5	25·0	22·5	20·0	16·0	12·0
300	—	—	46·0	42·0	38·5	35·5	32·5	28·5	25·5	22·5	19·0	15·5
350	—	—	48·0	44·0	40·5	37·5	34·5	31·0	27·5	25·0	21·5	18·0
400	—	—	—	46·0	43·0	40·0	37·0	33·0	30·0	27·0	23·5	20·0

As an example of the possible economies to be gained by resorting to back-pressure working with large steam turbo-electric units, reference may be made to the investigations of the Nitrogen Products Committee of the Ministry of Munitions (of which the Author was a member) into the problem of combining the generation of power on a large scale with the recovery of valuable by-products from the coal employed.

One of the systems examined involved the complete conversion of the coal into power gas by treatment in ammonia recovery producers, and the utilization of the surplus gas, after meeting the requirements of the producer plant, for firing the boilers in

the power house. In this system, a large quantity of low-pressure steam was needed for the requirements of the producer blast and for the ammonia recovery plant, the nett quantity to be supplied from external sources amounting to 1·63 tons per ton of coal gasified. Consideration was given to the alternatives of raising this steam in low-pressure boilers and of taking it from a low-pressure stage of the main turbines. Upon the basis of specific conditions with regard to the thermal efficiency of the gas-fired boilers in the power house and to the heat units required by the steam turbo-electric plant per K.W.H. at the switchboard, it was found that back-pressure working represented an economy of 20 per cent. in fuel consumption as compared with the alternative method of raising the low-pressure steam.

Full details of these investigations are set out in the Final Report of the Nitrogen Products Committee published at the beginning of this year (1920) (Cmd. 482).

TABLE LXI.

APPROXIMATE PRE-WAR COST PER K.W. OF RATED OUTPUT OF STEAM TURBO-GENERATORS COMPLETE WITH CONDENSERS AND PUMPS.

A. C. Generators.

Rated output.	High-pressure turbines.	Low-pressure turbines.	Mixed-pressure turbines.	Reducing turbines.
K.W.	£	£	£	£
200 to 500	8 to 4	7·5 to 3·7	8·5 to 5	8·5 to 5
500 ,, 1,000	4 ,, 3	3·7 ,, 2·7	5 ,, 3·4	5 ,, 3·4
1000 ,, 1,500	3 ,, 2·5	2·7 ,, 2·3	3·4 ,, 3	3·4 ,, 3
1500 ,, 2,000	4 ,, 2·7	3·7 ,, 2·4	5 ,, 3·7	5 ,, 3·7
2000 ,, 4,000	2·7 ,, 2·2	2·5 ,, 2·0	3 ,, 2·5	3 ,, 2·5
4000 ,, 8,000	2·7 ,, 2	2·6 ,, 1·9	2·9 ,, 2·2	—
8000 ,, 10,000	2 ,, 1·9	1·9 ,, 1·8	2·2 ,, 2·1	—
D. C. Generators.				
200 to 500	8·8 to 4·3	8·2 to 4·1	9·4 to 5·5	9·4 to 5·5
500 ,, 1,000	4·4 ,, 3·3	4·1 ,, 3·0	5·5 ,, 3·6	5·5 ,, 3·8
1000 ,, 1,500	4·5	4·2	4·6	4·7

Comparative Capital Costs.—The above Table, No. LXI., will be found useful for estimating purposes. It gives the approximate pre-war costs of turbo-generators of different types

together with their complete equipment of condensing plant. The prices are over considerable ranges, because they will vary with the type of condensing plant used, and will also vary, of course, with the conditions of contract, and with the price of materials at the time of tendering.

Design of Turbine Lay-out.—In laying out turbine installations, great care must be exercised in seeing that the steam-pipe system is well drained so as to prevent pockets of water being carried into the turbine; the superheat must be carefully regulated, especially with the reaction type; the oil system must be well designed, and the turbine and its generator most carefully balanced. Plate VIII. shows a typical lay-out of a turbine, with foundations and condenser basement. A bellows, or expansion piece, is generally fitted between the turbine and condenser when so placed, on account of the differences of expansion and of pressure with varying vacua. A special point in the design of a good turbine is accessibility for internal inspection and measurement of clearances without the removal of auxiliary details, such as governor levers, oil pipes, etc.

Reaction-type turbines have to be very carefully erected and lined up owing to the small clearances between fixed blades and rotor blades. On the other hand, owing to the greater difference of pressure between the (less numerous) stages of an impulse turbine, very small clearances can only be given between the shaft and the fixed diaphragms, so that unless the shaft is designed of sufficient strength, contact between these parts may arise. Means of checking the steam consumption of each turbine, such as a Lea Recorder, should be installed, as this enables the engineer on duty to see at once if any strips have taken place. Moreover, the apparatus is so simple and so cheap that it should always be fixed.

Air Filters.—The air filter is a necessary adjunct to all modern stations involving large turbo-alternators. These filters may be either of the wet or dry air type. The requirements of a good filter are that the supply of air to the alternator shall be clean and cool; clean, so that the small ducts through the stator core shall not become clogged with the myriads of small particles of dirt always present in the atmosphere, especially in

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industrial districts; cool, so that the effective output of the alternator may be maintained within the permissible limits of temperature. It is therefore customary to draw the air from without the station building, through the filter situated in a properly selected position in the engine-room basement. The filter delivers into a trunk formed in the concrete foundation, whence the air is drawn into the alternator casing. After passing through the air-spaces and ducts in the alternator, the air is finally delivered into the engine-room at the top of the alternator casing.

The wet type of filter ensures the cleanest air but care has to be exercised to prevent the discharge of moisture which will condense on the stator windings and so in time destroy the insulation. A type of wet air filter should therefore be chosen which avoids the use of sprays which will saturate the air passing through the filter. The Heenan stationary air filter, made by Heenan & Froude, Ltd., of Worcester, England, is such a type and has been used by the Author on many occasions and always with success. In this type the air is either drawn or forced through two sets of screens fitted one behind the other, the screens being formed of metallic wool closely packed between frames of expanded metal. A flow of water is continually passed over these screens, the water being delivered to the top of the first screen from a small auxiliary centrifugal pump which is fitted to the side of the filter. After percolating through the screen the water falls into a tank at the bottom of the filter whence it passes through a strainer and is recirculated by the pump. The water level in the tank is maintained by a float-valve so that the water lost by evaporation can be made up from the general water supply. The dirt brought down by the water from the screens can be removed by sludge doors. The screens are easily removed for cleaning purposes.

The air after passing through the screen then passes a series of felt-lined eliminators or baffles which catch and throw down any loose moisture which may have passed the second screen. The filter, two views of which are illustrated in Fig. 90, is designed in several standard sizes having capacities ranging from 1300 to 75,000 cubic feet per minute. The usual rating

is 42 cubic feet per minute per 100 kilowatts standard rating of the alternator.

Table No. LXII. (on opposite page) sets out the dimensions, shipping weights, and other leading particulars of some typical sizes (small, medium, and large).

Water Loads.—Power houses should be provided with means of testing any of the sets installed on separate load apart from the main power circuits. By doing this after periodical overhauls the economy of the plant can be maintained with the

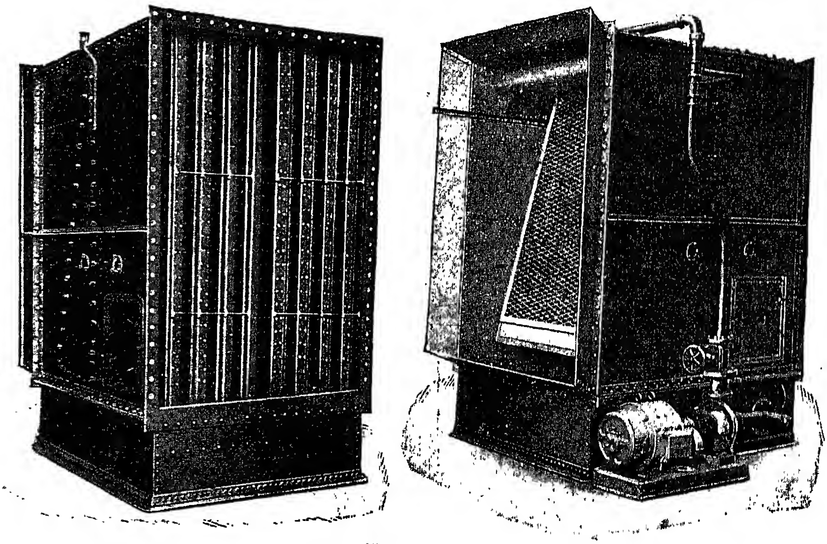


Fig. 90.

resulting economical production of energy. Water loads are usually provided for this purpose, and with high-tension plant these must be permanently and carefully arranged so as to prevent danger both to employees and to the plant itself.

The device designed by Messrs. Morcom and Walshe, consists simply of portable water-cooled inductive coils with variable cores, which are inserted in series with ordinary water tubs, or plates suspended in a pond or canal, and in which the inductance can be modified so as to bring about conditions of power factor in the load equivalent to those experienced under actual practical conditions.

TABLE LXII.

SIZES OF HEENAN STATIONARY AIR FILTERS.

Maximum capacity.	Rating of motor.	Shipping specification.		Relative humidity of air leaving filter.	Air entering filter.		Air leaving filter.		Water evaporated per 1000 cub. ft. of air per minute.
		Gross weight.	Cubage.		Dry bulb.	Wet bulb.	Dry bulb.	Wet bulb.	
cub. ft. per min. 1300	E.H.P. 0·5	lbs. 875	cub. ft. 50	per cent. 68	deg. F. 100	deg. F. 78	deg. F. 86·5	deg. F. 78	gals. per hour. 1·50
17,000	2·0	3030	389	71 80 85	90 80 70	72 68 62	79 72·5 65	72 68 62	1·25 0·90 0·55
75,000	6·5	16420	879	88 92	60 50	55 47	57 48·2	55 47	2 0·33 0·2

Fig. 91 gives a curve showing the temperature variation in the resistance of canal water. It is taken from a paper read by Messrs. Morcom and Davies before the Institution of Electrical

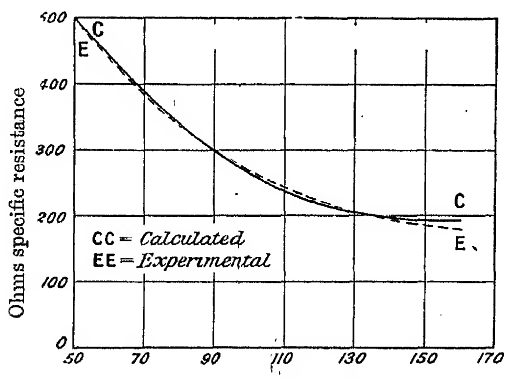


FIG. 91.

Engineers in 1908, and may be used as a basis of computation of the necessary sizes of artificial water loads. The calculated curve CC approximates very closely to the actual experimental

curve EE between 50° and 160° Fahr., a range which covers practical working. Table No. LXIII., from the same paper, sets out the particulars of certain waters tested by the authors.

TABLE LXIII.

SPECIFIC RESISTANCES OF VARIOUS WATERS.

Source.	Degree of hardness.	Mineral matter in solution.	Specific resistance at 60° Fahr.	
			Per cm.^{3}	Per ft.^{3}
	deg.	Parts in 100,000.	ohms.	ohms.
Distilled	—	—	600,000	20,000
Condensed from an engine .	—	About 2	66,000	2,170
[illegible] water . .	3·2	6·2	13,200	435
[illegible] tap, and 50% [illegible] nal . .	—	—	965	32
Birmingham canal . . .	52	143	435	14
Blackburn water . . .	—	—	17,000	560
Glasgow water	—	Particulars supplied by Mr. W. P. Digby	17,500	580
West London water . . .	—	—	2,800	92
Rugby water	—	—	2,400	79

CHAPTER VII

CONDENSERS

THERE are a few cases where an atmospheric exhaust is more economical than the adoption of condensers, as in very small power houses, or in larger power houses with poor load factors and cheap fuel. Such cases, however, are rare. Even in the latter instance a part of the plant, i.e. the long hour plant, should be provided with condensers. The saving in steam by using condensers varies from 20 to 25 per cent. in the case of reciprocating engines, but the whole question is, of course, a comparison of the capital cost of condensers, and the cost of running the auxiliary pumps, as against the cost of larger boilers and bigger consumption of fuel and water when exhausting to atmosphere.

There is another aspect affecting condensers. All large steam power houses are of course run condensing; and all turbine plants are necessarily so run, for the reason set forth in Chapter VI., when dealing with exhaust turbines. The cost of condensers for turbine plants is usually higher than with reciprocating plants, where an inch more or less of vacuum about 26 inches does not greatly affect economy. With a turbine plant, however, every inch tells on the economy of steam. This has already been mentioned in connection with reaction turbines (p. 201) and is clearly shown by the steam consumption curves in Fig. 92 which give the effect of varying vacua both for high-pressure and exhaust turbines. The degree of vacuum also affects the size of condenser in any given case and the cost of pumping the necessary amount of circulating water.

Thus, every power house has its own peculiar economic

problems, which a skilful designer must work out in order to get the most satisfactory result. The items affected are :—

(*a*) Capital cost of boiler plant, including buildings.
(*b*) Capital cost of condensing plant.
(*c*) Cost of fuel.
(*d*) Annual load factor.

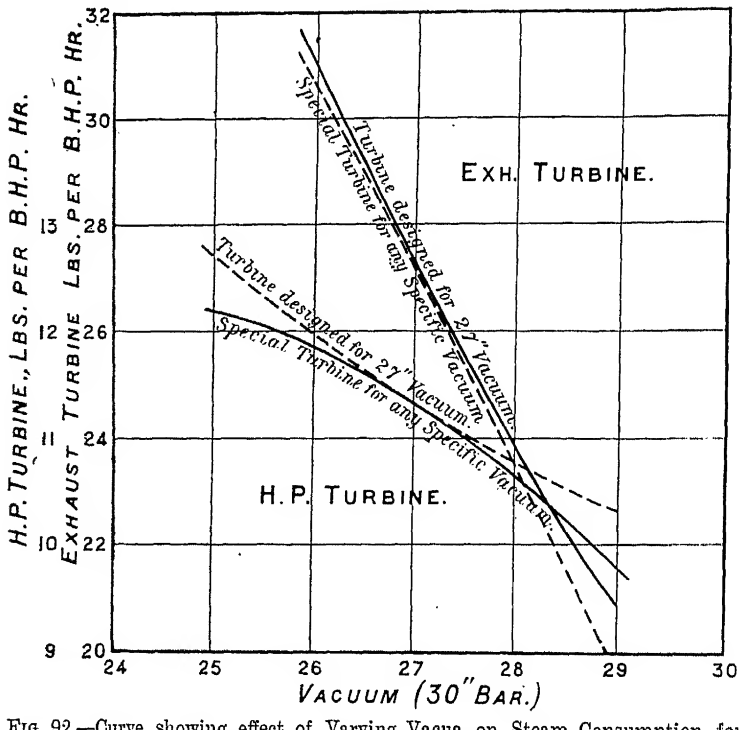


FIG. 92.—Curve showing effect of Varying Vacua on Steam Consumption for Exhaust and H.P. Turbines.

(*e*) Running cost of power house, which determines the cost of running condenser auxiliaries. The latter increases materially at the higher vacua.

A paper read by Mr. R. M. Neilson before the Institution of Electrical Engineers (England) in 1909 (Vol. 44, 1910), contains a series of curves showing the effects of varying vacua upon the economy of a steam turbine power house taking condensing water from cooling towers. The curves indicate the

difference between certain costs at any vacuum and the corresponding costs at a vacuum of 27 inches, and thus the resultant effect upon the cost of the energy available for sale. The costs in question are those affected by the degree of vacuum and relate to the boiler plant, the condensing plant and the coal consumed.

The data on which the curves are based are as follows:—

(*a*) Boiler plant, including erection, taken at a cost of £3·5 per K.W. for a 27-inch vacuum; depreciation, repairs, and maintenance taken at 10 per cent., and interest, rates, and taxes at 7 per cent.

(*b*) Condensing plant with cooling towers and accessories, taken at a cost of £1·4 per K.W. for a 27-inch vacuum; de-

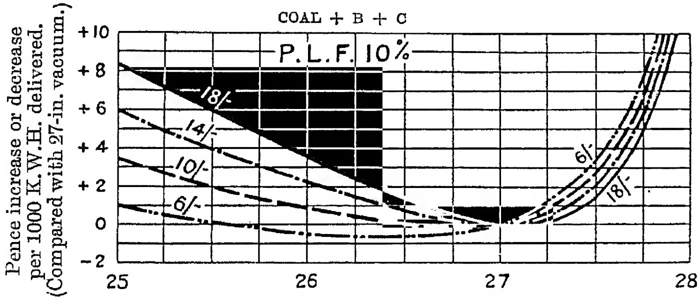


Fig. 93.

preciation, repairs, and maintenance at 10 per cent., and interest, rates, and taxes at 7 per cent.

(*c*) Coal, taken at varying prices, and in all cases of a calorific value of 13,000 B.Th.U. per lb., the steam consumptions of the turbines being based on known results from high-class plant.

Fig. 93, taken from the above-mentioned paper, gives the resultant curves for a plant load factor of 10 per cent. which have been checked by the Author. Similarly Figs. 94 and 95 give the resultant curves for plant load factors of 20 per cent. and 30 per cent.

In all cases, the curves were obtained by amalgamating individual curves for coal, boiler plant, and condensing plant

plotted with respect to a 27-inch vacuum as the datum. The other points on the curves were obtained by taking account of the varying steam consumptions on either side of that vacuum, the varying power requirements of the condenser auxiliaries,

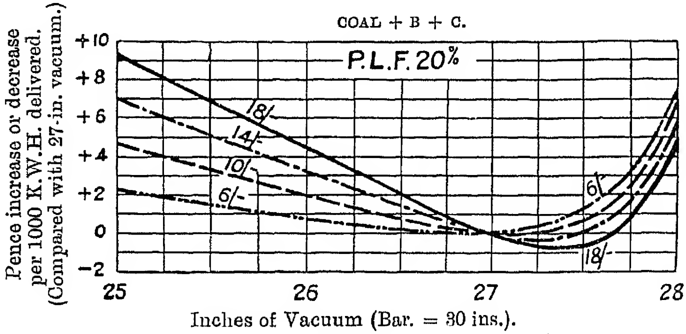


FIG. 94.

the varying temperatures of the hot well water and consequent increases or decreases in the capacity of the boiler plant and in the cooling surface and therefore the size of the condensing plant. As previously stated, the curves are based on conditions at a power house using cooling towers.

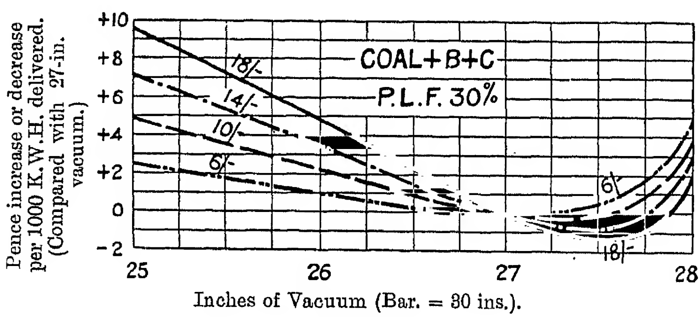


FIG. 95.

Types of Condensers.—There are several available types of condenser, viz. the low-level jet condenser, the siphon, the barometric jet, the surface condenser, and the ejector condenser.

The efficiency of any condenser depends on the removal of the air and incondensible gases which either come over with the steam or from leakage or other sources.

Simple Jet Condensers.—The simple jet condenser has the advantage that only one pump is required, but the pump has to remove both the injection water and the condensed steam. This type has the disadvantage that the heat units in the exhaust are lost for boiler feed.

The injection water is obtained by means of the atmospheric pressure, and the discharge pump lifts the water to the outlet level or to the top of cooling towers, as may be necessary. The effective head from the latter is usually 25 feet neglecting pipe friction, but will vary, of course, with the relative positions of the condenser and tower. Fig. 96 shows a section through a Le Blanc simple-jet condensing plant, and Fig. 97 a sectional plan. The exhaust steam enters the condenser at A, passes down and meets the cooling water injected by the Pelton wheel. The steam and injection water are thoroughly mixed, and owing to the high velocity given to the injection water by the wheel, the combined water and condensed steam are swept out against the atmospheric pressure, while creating and maintaining a high vacuum. This plant is always arranged so that it has to lift its injection water, and the Pelton wheel must therefore be primed; this is done by means of a steam starting ejector shown at C in the figure. If the water supply is under pressure, this ejector is, of course, unnecessary. In this type of condenser, the discharge from the wheel is intermittent, consisting of so many separate sheets of water shot out by the wheel blades, as shown in Fig. 96. Thus the air is entrapped between successive sheets and so delivered with the discharged water. It is claimed that from six to ten volumes of air are removed by one volume of water. The limiting size is about 500 K.W.

Multiple Jet Condensers.—This type is adopted for larger units of plant. A sectional arrangement is shown in Fig. 98. The steam enters at the inlet A and the injection water at B, the latter passing into a distributing chamber C, and discharging into the condenser through the nozzles D. The nozzles are specially designed and fitted with vanes which split up the water jets and impart a swirling motion to them, so as to increase the area of contact with the steam. The cone E is fixed

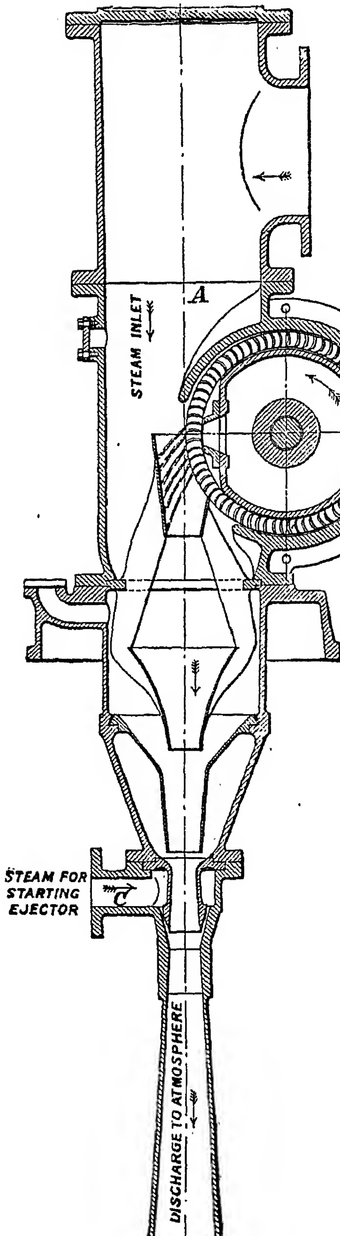

A
STEAM INLET
STEAM FOR
STARTING
EJECTOR
C
DISCHARGE TO ATMOSPHERE

FIG. 96.

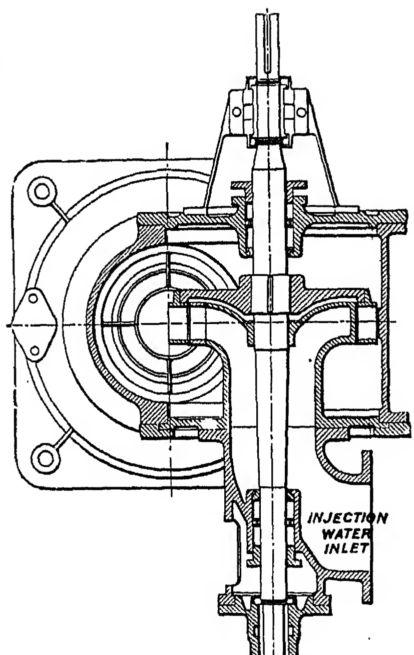

INJECTION
WATER
INLET

FIG. 97.

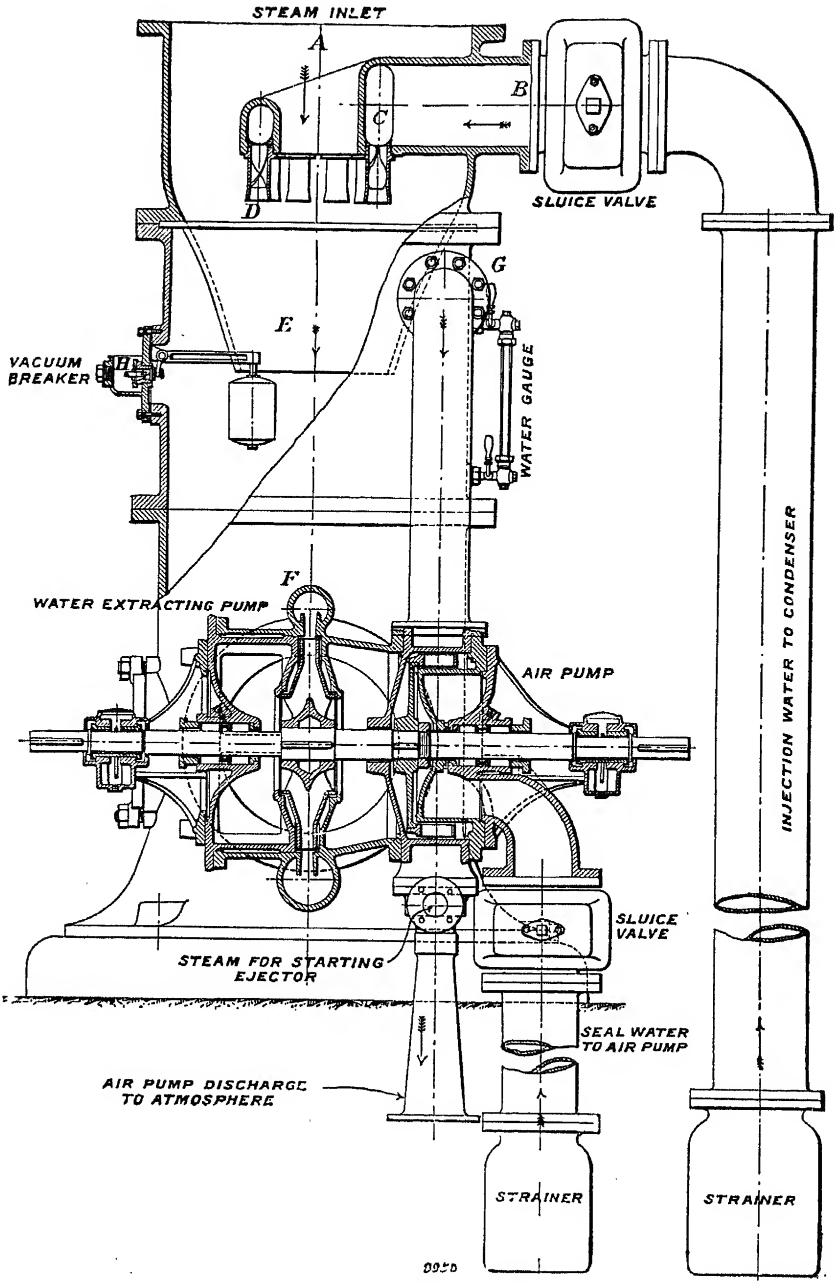

STEAM INLET
A
B
C
D
SLUICE VALVE
E
G
VACUUM BREAKER
H
WATER GAUGE
INJECTION WATER TO CONDENSER
F
WATER EXTRACTING PUMP
AIR PUMP
SLUICE VALVE
STEAM FOR STARTING EJECTOR
SEAL WATER TO AIR PUMP
AIR PUMP DISCHARGE TO ATMOSPHERE
STRAINER
STRAINER

FIG. 98.

so as to narrow the area through which the steam and water pass, thus causing them to mix intimately and producing rapid condensation. The combined steam and water fall to the bottom of the condenser, and are discharged by the wet pump F. The air and incondensible gases separate from the water, and are drawn off by the dry air pump through the suction pipe G. In the type illustrated there is removed a great objection to the ordinary low-level jet condenser. In the latter water may pass back to the engine or turbine and wreck it, should the pump fail. As will be seen from Fig. 98, this danger cannot arise with the type of plant illustrated. There is an uninterrupted passage through the pump, so that if the pump should stop air rushes into the condenser through the air pump and immediately breaks the vacuum.

There is also an air valve, shown at H, controlled by a ball float, which rises with the water when it reaches a certain level, opens the valve admitting air to the condenser, and thus breaks the vacuum.

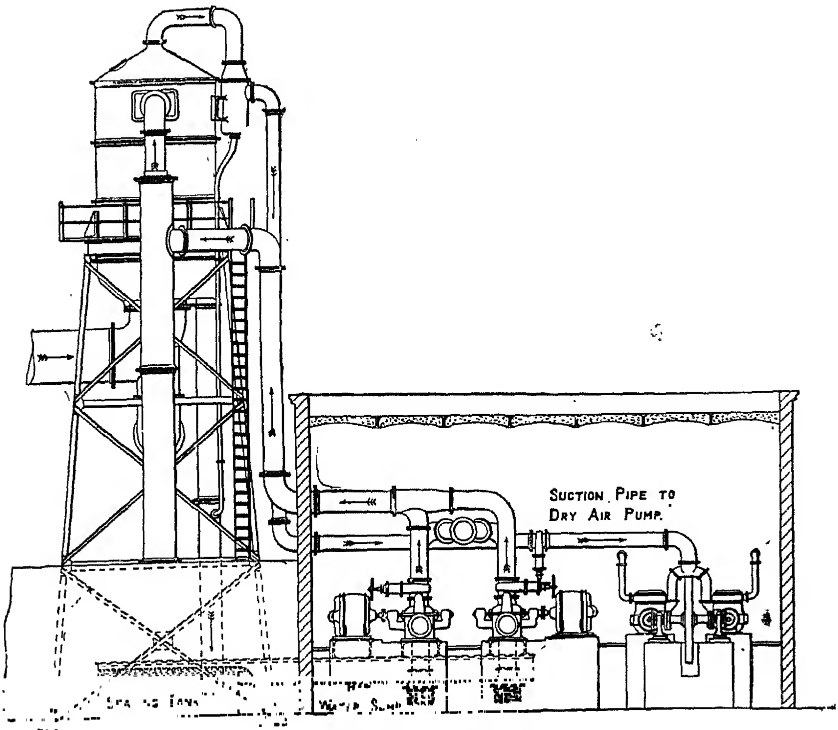
The following Table, No. LXIV., gives the leading particulars of this type of condenser.

TABLE LXIV.

MULTIPLE JET CONDENSERS.

Type No.	Normal steam duty with cooling water at 60° Fahr.	Approximate power required.	Speed of pumps.	Maximum discharge lift of water-extracting pump.
	lbs. per hour.	B.H.P.	R.P.M.	feet.
1	7,000	12	960	26
2	8,800	15	960	,,
3	10,500	18·5	960	,,
4	10,500	18·5	960	,,
5	13,200	23	960	,,
6	16,000	27	960	,,
7	16,000	27	720	,,
8	19,600	33	720	,,
9	23,800	39	720	,,
10	23,800	39	720	,,
11	30,000	47	720	,,
12	35,000	55	720	,,
13	35,000	55	480	,,
14	45,000	70	480	,,
15	53,000	85	480	,,
16	53,000	90	480	,,
17	65,000	100	480	,,
18	80,000	115	480	,,

Siphon Condensers.—The siphon type of barometric condenser is a modification of the simple jet condenser. The condenser head is fixed at a height of not less than 34 feet above the hot well, and a pipe connects this chamber with the hot well where the end is water-sealed. The inside of the tube is contracted into a throat at the point where the steam and in-

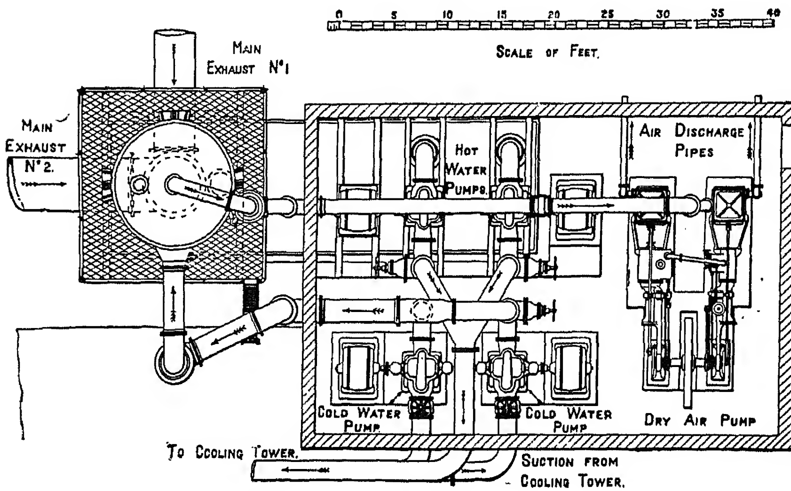


Sectional Elevation.
Fig. 99.

jection water mix, so that the increased velocity of the water through the throat carries the air and vapour with it, and no air pump is needed. The barometric pressure prevents the water from backing into the engine.

Barometric Condensers.—The barometric type shown in Figs. 99 and 100 is similar to the siphon type, but has the addition of a dry air pump, which is connected to the top of the

condenser head, and extracts air and vapour at the best point for so doing. Both these types require but small floor space, are of extremely simple construction, and are cheap in first cost. As, however, they necessarily have to be fixed away from the turbines, an addition has to be made to their cost for the very large exhaust connecting pipe between the turbine or engine and the condenser, and also an allowance for the loss of vacuum due to friction in the pipe. The barometric types also require somewhat expensive steel framework to support the condenser head and barometric head.



Plan.

Fig. 100.

As the name implies, the discharge water cannot flood the exhaust range unless the injection water fed into the condenser head should exceed the amount which the vertical pipe is capable of discharging. Such a condition may arise on a high vacuum due to the sudden increase in the speed of the injection pump.

The power required to drive the pumps is approximately 75 per cent. of the power required for ordinary low-level jet condensers without external head of water, but is practically the same when working with cooling towers.

In fixing the heights of barometric condensers it must be remembered that each 1 lb. below atmospheric pressure is equivalent to a water column of 27·68 inches, and therefore, for the usual atmospheric pressure of 14·7 lbs., the equivalent height is 33·9 feet.

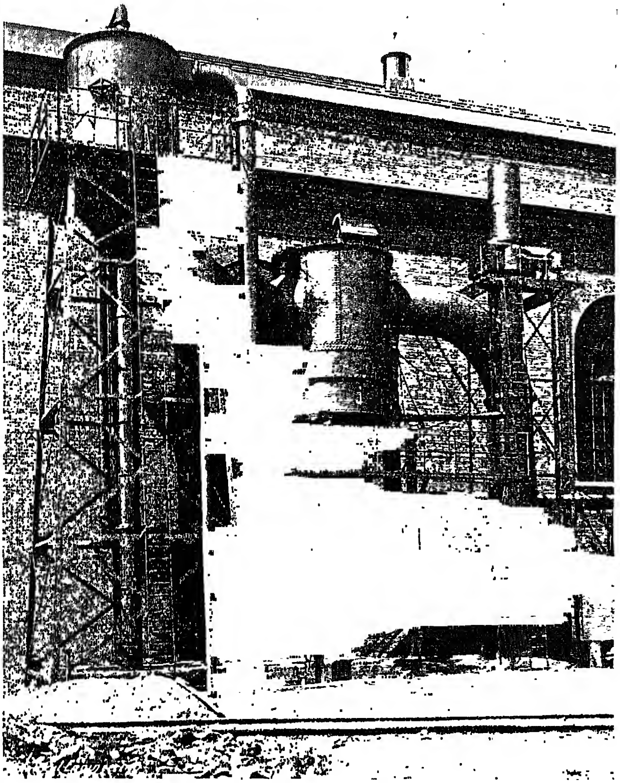


Fig. 101.

Fig. 101 shows a barometric condenser at the Central Railway Company's power house, London, coupled to a 9000 K.W. steam generator. It is of the vertical counter current design with a volumetric capacity of 530 cubic feet. It is fitted with a series of trays and baffles for distributing the cooling water,

The tail pipe leading to the hot well is 15 inches in diameter, and the exhaust pipe from the engine is 26 inches in diameter. An exhaust oil separator is fixed immediately in front of the condenser, the oil from the exhaust being withdrawn by a small steam pump which lifts the oil to a separating tank. This condenser is coupled to a brick natural draught cooling tower, having a shaft 24 feet in diameter by 115 feet in height. The tower base is 79 feet by 31 feet, and the inlet water is raised to a level of 26 feet from the foundation.

TABLE LXV.

BAROMETRIC COUNTER-CURRENT JET CONDENSERS FOR RECIPROCATING ENGINES.

(Vac. at engine = 26″. Vac. at condenser = 26¼″. Barometer = 30″.)

Output of engine.	Approximate steam consumption.	Injection water at 60° Fahr.					Cooling tower water at 80° Fahr.				
		Condenser.		Gallons per hour.	Approximate B.H.P. of air and injection pumps.	Approximate pre-war cost erected with framework.	Condenser.		Gallons per hour.	Approximate B.H.P. of air, injection and H.W. pumps	Approximate pre-war cost erected with framework.
		Length.	Width.				Length.	Width.			
K.W.	lbs. per hr.	ft. ins.	ft. ins.			£	ft. ins.	ft. ins.			£
200	5,000	7 0	2 6	8,750	2·4	335	7 0	3 0	13,250	9·4	410
300	7,500	7 0	3 0	13,100	6·4	380	10 0	3 6	19,850	13·9	600
400	9,600	9 0	3 0	16,800	8·2	420	10 0	4 0	25,400	17·8	740
500	12,000	10 0	3 6	21,000	10·1	460	12 0	4 0	31,800	22·1	865
750	17,000	10 0	4 0	29,000	14·1	515	15 0	4 6	45,000	30·7	1020
1000	20,000	12 0	4 0	35,000	16·5	570	16 6	4 6	53,000	36·2	1140
1250	25,000	15 0	4 6	43,700	20 7	645	17 0	5 0	66,200	44·0	1290
1500	30,000	16 6	4 6	52,500	24·6	705	17 0	5 6	79,500	52·0	1420
1750	35,000	16 0	5 0	61,300	28·5	765	17 0	6 0	92,600	59·9	1565
2000	47,500	17 0	5 0	66,500	30·9	830	18 0	6 0	100,500	64·1	1735
2500	47,500	17 0	5 6	83,000	38·6	890	20 0	6 6	126,000	78·3	1900
3000	57,000	18 0	6 0	99,500	46·2	980	24 0	6 6	151,000	93·0	2095

NOTE.—The above figures and prices are based on standard plant working under average conditions, and must only be considered as very approximate, as each plant requires special consideration depending on circumstances.

The prices include (in the case of plant designed for water at 60° Fahr.) condenser, staging, injection and air pumps, one motor and suitable switchgear, the piping connecting pumps and condenser only, and delivery and erection on purchaser's foundations. (For plants designed for 80° Fahr. water, one hot well pump, cooler and extra motor are included.)

The above Table, No. LXV., prepared for the Author by the courtesy of Messrs. Balcke & Co., gives the pre-war

cost of various sizes of barometric condensers, for use with reciprocating engines, to maintain a 26¼-inch vacuum (Bar. 30 inches), complete with pumps and tanks; and also the percentage of power required to drive the auxiliaries.

Similarly, Table No. LXVI. gives corresponding particulars of barometric condensers for use with turbines, to maintain a 28¼-inch vacuum (Bar. 30 inches).

TABLE LXVI.

BAROMETRIC COUNTER-CURRENT JET CONDENSERS FOR STEAM TURBINES.

(Vac. at turbine = 28″. Vac. at condenser = 28¼″. Barometer = 30″.)

Output of turbine.	Approximate steam consumption.	Injection water at 60° Fahr. Condenser. Length.	Injection water at 60° Fahr. Condenser. Width.	Injection water at 60° Fahr. Gallons per hour.	Injection water at 60° Fahr. Approximate B.H.P. of air and injection pumps.	Injection water at 60° Fahr. Approximate pre-war cost erected with framework.	Cooling tower water at 75° Fahr. Condenser. Length.	Cooling tower water at 75° Fahr. Condenser. Width.	Cooling tower water at 75° Fahr. Gallons per hour.	Cooling tower water at 75° Fahr. Approximate B.H.P. of air injection and H.W. pumps.	Cooling tower water at 75° Fahr. Approximate pre-war cost erected with framework.
K.W.	lbs. per hr.	ft. ins.	ft. ins.			£	ft. ins.	ft. ins.			£
200	5,000	9 0	3 0	15,900	7·3	400	10 0	4 0	29,200	19·8	810
300	7,000	10 0	3 6	22,300	10·4	435	12 0	4 6	41,000	27·1	1160
400	9,000	10 0	4 0	28,600	12·4	505	16 6	4 6	52,600	34·3	1515
500	11,000	12 0	4 0	35,000	15·5	550	17 0	5 0	64,300	41·4	1855
750	16,000	16 6	4 6	51,000	22·0	655	17 0	6 0	93,500	58·3	2195
1000	21,000	17 0	5 0	66,800	28·7	755	20 0	6 6	123,000	76·8	2565
1250	25,000	17 0	5 6	79,500	33·4	860	24 0	6 6	146,000	87·6	2965
1500	29,000	17 0	6 0	92,200	38·5	970	21 6	7 0	170,000	101·9	3390
1750	33,000	18 0	6 0	105,000	43·6	1040	24 6	7 0	193,000	114·6	3765
2000	36,000	19 0	6 0	114,500	47·9	1130	27 0	7 0	212,000	122·7	4160
2500	45,000	24 0	6 6	143,000	59·5	1325	27 0	7 6	263,000	152·6	4560
3000	54,000	21 6	7 0	172,000	71·4	1500	27 0	8 0	316,000	176·7	4950

NOTE.—The above figures and prices are based on standard plant working under average conditions, and must only be considered as very approximate, as each plant requires special consideration depending on circumstances.

The prices include (in case of plant designed for water at 60° Fahr.), condenser, staging, injection and air pumps, one motor and suitable switchgear, the piping connecting pumps and condenser only, and delivery and erection on purchaser's foundations. (For plants designed for 75° Fahr. water, one hot well pump, cooler, and extra motor are included.)

In the barometric type as in the jet condenser, the heat units in the condensed steam are largely lost, and, moreover, when auxiliary cooling towers have to be adopted, there are additional heat units to be got rid of in the cooling tower in

order to preserve the same average temperature of injection water.

Surface Condensers.—Condensers of the surface type, as

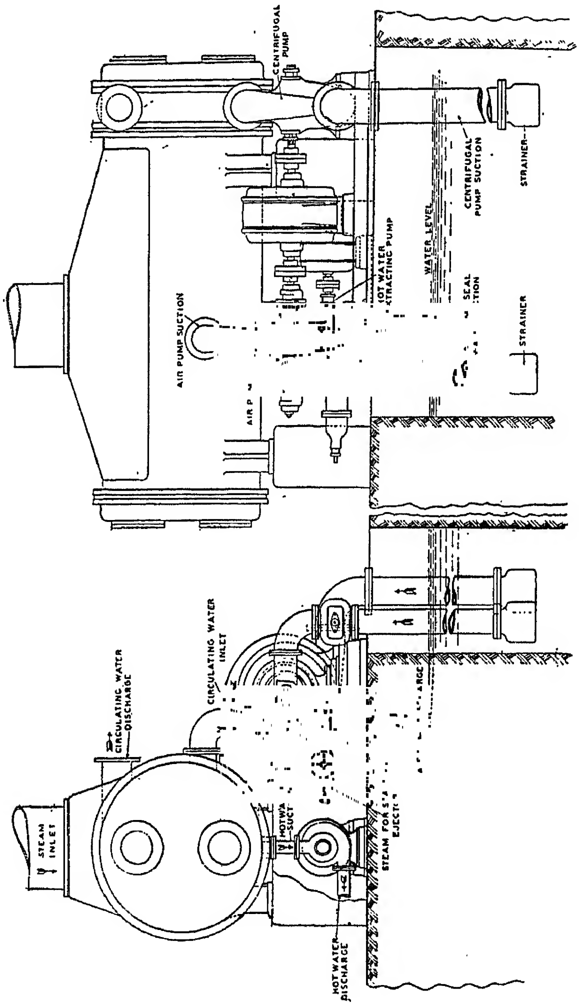


FIG. 102.
(*From Manchester Association of Engineers.*)

shown in Fig. 102, are most frequently used in power houses, especially of the larger kinds. They can be readily accommodated immediately below the turbine or engine, thus ensuring

the best vacuum in the low-pressure cylinder or expansion stage. Moreover, the condensed steam or hot-well discharge can be used again for boiler feed, a most important item in economy, representing generally the difference between boiler feed temperatures of 60° Fahr. and 110° Fahr. (or 50° Fahr.), and a saving of roughly 5 per cent. in the coal consumption.

The disadvantages of the surface condenser are:—

(*a*) Increased first cost.

(*b*) Comparative inefficiency owing to the interposition of the tubes between the steam and the circulating water. The discharged circulating water rarely approaches nearer than some 15° Fahr. to the temperature of the exhaust steam on average runs.

(*c*) The cost of cleaning and of repairs. This is practically negligible, however, when working on a turbine plant and with good circulating water.

There are several types of surface condensers, such as Morrison's Contra-flow, Le Blanc, Parsons' augmenter type, and others. They are made in various forms, usually horizontal with cylindrical bodies but sometimes with horizontal rectangular bodies or vertical with circular sections.

The ordinary marine type usually has an allowance of 1·15 square feet of tube surface per K.W. output for steam generators of the reciprocating type, and 1·05 square feet for turbo-generators. The tube surface has, however, to be specially fixed according to the conditions (i.e. whether the circulating water is drawn from a natural source, or whether it is recooled in towers), and, of course, is also dependent on the average inlet temperature.

Parsons uses an augmenter with some of his surface-condensing plants: this consists simply of a small steam ejector which supplements the work done by the ordinary air pump, but is instrumental in maintaining a very high percentage vacuum.

Several practical points have to be considered in the construction of surface condensers. The exhaust steam inlet should be so arranged as to give the steam access to the tubes without throttling; the tubes should be carefully tinned inside and out; the partition at the end chamber dividing the water

TABLE LXVII.

Counter-current Surface Condensers for Reciprocating Engines.

Steam pressure 150 lbs. per sq. in. Superheat 150° F.

Vacuum at condenser = 26″. Barometer = 30″.

Output of engine.	Approximate steam consumption (150 lbs. pressure, and 150° F. superheat).	Cooling water at 60° Fahr.							Cooling water at 80° Fahr.					
		Condenser.		Tube surface.	Gallons per hour.	Approximate B.H.P. of pumps.	Approximate cost of plant with erection (pre-war).		Condenser.		Tube surface.	Gallons per hour.	Approximate B.H.P. of pumps.	Approximate cost of plant with erection (pre-war).
		Length.	Diameter.						Length of tubes.	Diameter of tube plate.				
K.W.	lbs. per hr.	ft. ins.	ft. ins.	sq. ft.			£		ft. ins.	ft. ins.	sq. ft.			£
200	4,500	4 0	2 3	225	14,400	5	462		3 6	2 9	320	20,300	7·5	580
300	6,700	3 9	2 9	335	21,500	6·5	600		5 6	2 9	480	30,300	10·5	660
400	8,700	5 0	2 9	435	27,900	8·5	640		4 6	3 3	625	39,300	14	820
500	9,500	5 3	2 9	475	30,400	9	660		5 0	3 3	680	42,800	15	840
750	13,500	5 0	3 3	675	43,200	12	835		7 0	3 3	960	60,800	20	970
1000	17,000	6 3	3 3	850	54,400	15	910		6 9	3 9	1220	76,500	25	1100

The approximate B.H.P. of the pumps in the case of cooling water at 60° Fahr. is based upon a total head (inclusive of pipe and condenser friction) of 20 feet, and in the case of cooling water at 80° Fahr. on a head of 30 feet.

The approximate costs under the heading "Cooling water at 80° Fahr." do not include any form of cooling apparatus.

TABLE LXVIII.

Counter-current Surface Condensers for Steam Turbines.

Steam pressure 200 lbs. per sq. in. Superheat 200° F.
Vacuum at condensers = 28″. Barometer = 30″.

Output of turbine.	Approximate steam consumption (200 lbs. pressure and 200° F. superheat).	Cooling water at 60° Fahr.						Cooling water at 75° Fahr.					
		Condenser.		Tube surface.	Gallons per hour.	Approximate B.H.P. of combined pumps.	Approximate cost erected with pumps. (pre-war).	Condenser.		Tube surface.	Gallons per hour.	Approximate B.H.P. of combined pumps.	Approximate cost erected with pumps (pre-war).
		Length of tubes.	Diameter of tube plate.					Length of tubes.	Diameter of tube plate.				
K.W.	lbs. per hr.	ft. ins.	ft. ins.	sq. ft.			£	ft. ins.	ft. ins.	sq. ft.			£
200	4,000	3 9	2 9	330	16,000	5	500	5 0	2 9	450	28,000	9	645
300	5,700	5 6	2 9	480	22,800	7	660	4 9	3 3	640	39,900	13	815
400	7,200	6 9	2 9	600	28,800	8	730	5 9	3 3	800	50,400	17	895
500	8,500	5 3	3 3	710	34,000	9	850	7 0	3 3	950	59,500	20	970
750	12,000	7 3	3 3	1000	48,000	13	980	7 3	3 9	1340	84,000	26	1150
1000	15,000	6 9	3 9	1250	60,000	16	1120	9 0	3 9	1670	105,000	33	1290
1250	18,000	8 0	3 9	1500	72,000	19	1225	8 3	4 3	2000	126,000	40	1440
1500	22,000	7 6	4 3	1840	88,000	24	1375	10 0	4 3	2450	154,000	48	1600
1750	25,000	8 6	4 3	2080	100,000	30	1460	9 6	4 6	2780	175,000	57	1700
2000	28,000	9 6	4 3	2330	112,000	37	1570	10 9	4 6	3100	196,000	69	1780
2500	35,000	10 0	4 6	2920	140,000	46	1750	10 9	5 0	3900	245,000	85	2000
3000	40,000	9 3	5 0	3340	160,000	51	1900	12 3	5 0	4450	280,000	95	2150
5000	64,000	12 6	5 6	5330	256,000	79	2700	13 6	5 9	7100	448,000	150	3000
10 000	125,000	12 9	7 3	10,400	500,000	146	5000	15 6	8 3	13,900	875,000	285	5900
15,000	180,000	14 3	8 3	15,000	720,000	205	7400	14 6	9 3	20,000	1,260,000	405	8600
20,000	230,000	14 0	9 6	19,200	920,000	265	8500	15 0	10 3	25,600	1,610,000	520	11000
25,000	270,000	13 6	10 6	22,500	1,080,000	315	10000	15 0	11 3	30,000	1,895,000	610	13000

The footnote to Table No. LXVII. with regard to the B.H.P. of the pumps applies to the above figures also. The horse-powers given assume the use of the Edwards type air pumps for the smaller sizes up to about 1500 K.W. and the use of rotary air pumps above that size.

The approximate costs under the heading "Cooling water at 75° Fahr." do not include any form of cooling apparatus.

space should be of wrought metal, and not cast; the end door should be secured by bolts at that point as well as at the flange, so as to prevent deformation, especially when the pump is delivering against a cooling tower head through the condenser. This, by the way, is not good practice, and it is better to let the water flow or be sucked through from the cooling pond by the pump so as to remove this head of water. The condenser should be connected to the turbine by a "concertina" to take up differences of expansion, or bolted rigidly to the exhaust flange and mounted on springs.

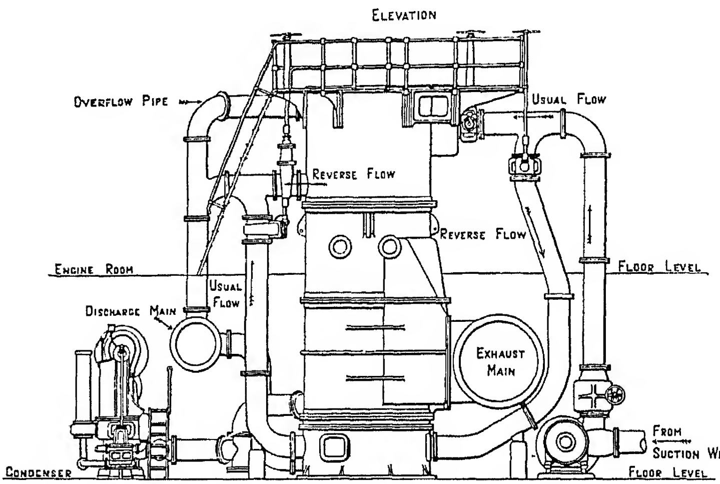


FIG. 103.

Tables Nos. LXVII. and LXVIII. set out the dimensions, approximate pre-war costs, and other leading particulars of counter-current surface condensers, as manufactured by Messrs. W. H. Allen, Son, & Co. of Bedford, England, for use respectively with reciprocating engines and with turbines.

Vertical Surface Condensers for Dirty Water.—Figs. 103 and 104 show an elevation and plan respectively of a vertical condenser with a cylindrical body made by the Mirrlees Watson Co., of Glasgow, for the Leeds Corporation power station, where the circulating water is dirty, being drawn from a neighbouring small river containing at certain seasons of the year many leaves

as well as straw and other materials. The tubes are larger in diameter than usual, being $1\frac{1}{8}$ inch external, instead of the more usual $\frac{3}{4}$ inch. There are 11,000 square feet of cooling surface, and the water passes only once through the full length of the condenser. The plant is designed to deal with 65,000 lbs. of

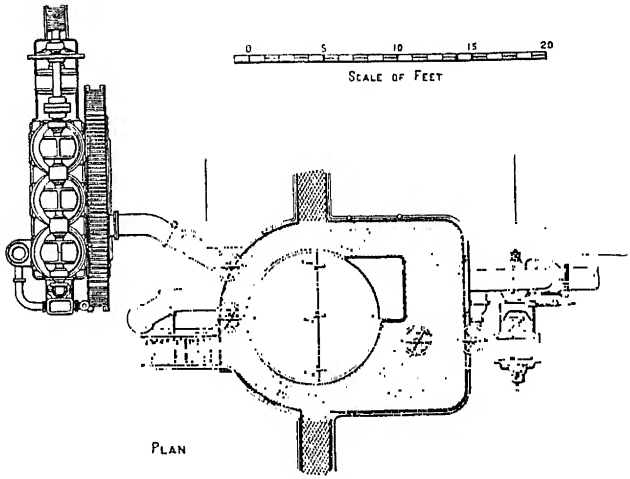


Fig. 104.

steam per hour, giving a vacuum of 28 inches (Bar. 30 inches) with condensing water at a temperature of 60° Fahr. The air pumps are three-throw Mirrlees-Edwards.

A test was taken after running in the power house for over twelve months with the results shown in Table No. LXIX. :—

TABLE LXIX.

Tests at Leeds with Vertical Surface Condenser.

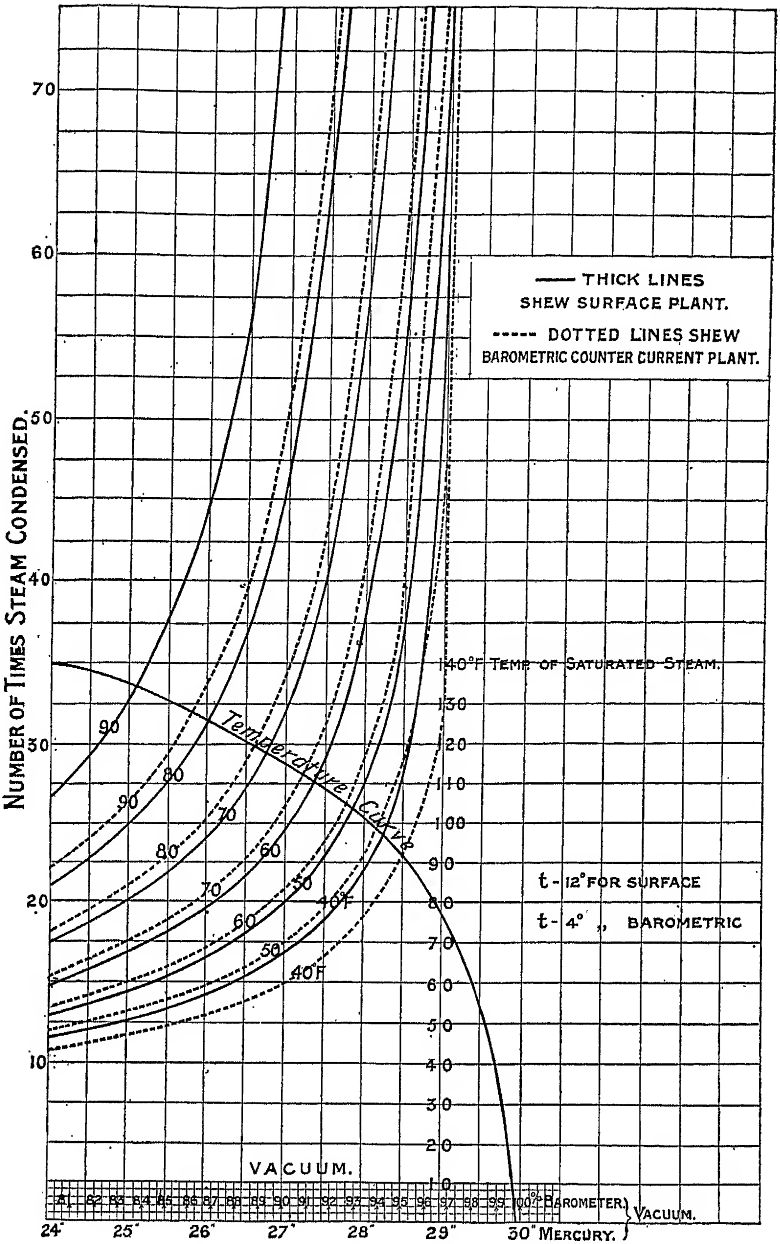
Load on plant.	Barometer.	Vacuum.	Equivalent vacuum with bar. 30″.	Temperature of circulating water. Inlet.	Temperature of circulating water. Outlet.	Temp. of air-pump discharge.
lbs. of steam per hour.	ins.	ins.	ins.	deg. Fahr.	deg. Fahr.	deg. Fahr.
30,000	29·4	28·25	28·85	62	78	88
30,000	29·4	28·30	28·90	62	78	87
30,000	29·5	28·25	28·75	61	76	86
30,000	29·4	28·40	29·00	60	76	86

Quantity of Circulating Water with Condensers. — The amount of circulating water is less in jet condensers than with surface condensers, and this is especially marked at high vacua. An average difference of temperature between the exhaust steam and the discharge water of jet condensers may be taken at 3·5° Fahr. As an example, let the vacuum maintained be 27 inches (90 per cent.), and the temperature of the injection water 80° Fahr. The temperature of steam at an absolute pressure of 1·5 lbs., equivalent to 27-inch vacuum, is 114° Fahr., and the equivalent total heat of saturated steam is 1116 B.Th.U. The temperature of the discharge water will thus be 114° – 3·5°, or 110·5° Fahr. Each pound of water passing through the condenser is raised from 80° to 110·5° and absorbs 30·5 B.Th.U. The amount of injection water required by a jet condenser will thus be $\frac{1116 - 110 \cdot 5}{30 \cdot 5}$, or nearly 33 times the weight of steam condensed, a very much less quantity than would be possible with surface condensers. This is most important when cooling towers are required as auxiliaries, as the capital cost of the plant is reduced, and the running cost of and power absorbed by the pumps are much less.

The quantity of circulating water in a surface condenser on a 27-inch vacuum with injection water at a temperature of 60° Fahr. will be as follows. The temperature of the exhaust steam is 114° Fahr., and the total heat 1116 B.Th.U. per lb. The discharged water will have a temperature under the best conditions of 114° – 15° or 99° Fahr., so that each pound of circulating water will take up 99 – 60 or 39 B.Th.U. The quantity of circulating water to condense 1 lb. of steam will thus be $\frac{1116 - 99}{39}$, or approximately 26 lbs. If the temperature of the circulating water were 80° Fahr., the quantity would be 53·5 lbs. per lb. of steam condensed, and this figure may be compared with that given above for the jet condenser.

Fig. 105 gives curves by W. N. Bailey, showing the quantity of circulating water required for surface and for barometric condensers.

De-oiling Apparatus for Condensers.—With reciprocating



THICK LINES SHEW SURFACE PLANT.
DOTTED LINES SHEW BAROMETRIC COUNTER CURRENT PLANT.
NUMBER OF TIMES STEAM CONDENSED.
70
60
50
40
30
20
10
140°F TEMP. OF SATURATED STEAM.
130
120
110
100
90
80
70
60
50
40
30
20
10
Temperature Curve
t - 12° FOR SURFACE
t - 4° „ BAROMETRIC
90
80
70
60
50
40°F
VACUUM.
81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 100% BAROMETER.
VACUUM.
24" 25" 26" 27" 28" 29" 30" MERCURY.

FIG. 105.

engine plants it is necessary to prevent the oil taken over by the exhaust steam from being deposited in the condenser tubes, as this would reduce considerably the effective transmission of heat from the steam to the water. The removal of the oil can to some extent be secured by interposing an exhaust separator with

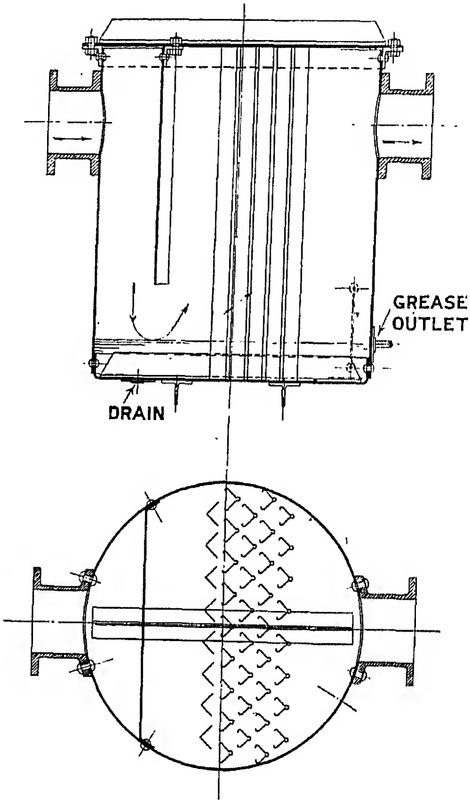


Fig. 106.

a suitable set of baffles, as shown in Fig. 106. By these means the velocity of the exhaust steam is reduced, and the oil is deposited in the separator, from which it can be removed by small auxiliary pumps.

Advantages of Separate Wet and Dry-air Pumps.—The old practice was to remove both the condensed steam and the air

and incondensible gases by the same pump. There are two objections to this, viz. (*a*) the air is not withdrawn from the condenser at the most effective point; and (*b*) the water discharged to the hot well becomes aërated, and is repumped in that condition into the boilers. It is better practice to have two separate pumps, viz. a wet pump withdrawing the condensed steam from the lowest point of the body, and a dry-air pump to remove the air and other incondensible gases from the upper portion of the condenser body.

Steam and Electrically-driven Air Pumps.—Some designers prefer steam-driven, others electrically driven pumps. The former claim that a failure of the pumps, and therefore of the vacuum, so seriously affects the whole plant, that it is preferable to drive the pumps from the boilers direct, even at the expense of some economy, rather than through the intermediary of engines, generators, and switchgear. The latter claim that with proper safeguards the risk of failure of supply to these auxiliaries is negligible, and that it is more economical to adopt electrical pumps, since donkey steam pipes and complication of the pipe lay-out are avoided, and the plant load factor is also improved.

In steam-driven sets, the amount of steam required to drive the condenser engine (if compounded) is usually about 2·5 per cent. of the total steam condensed by the set; the steam consumption of the condenser engine being about 18 lbs. per I.H.P. hour. The exhaust steam from these auxiliaries should preferably be taken through exhaust feed-water heaters in series with the economisers.

Electrically driven pumps have the advantage of higher speeds and greater ease of installation, and their use leads to simplicity in the design of the power house. In turbine-driven plants the power required for the pumps is some 3·5 to 4 per cent. of the total rated load on the plant, and in reciprocating plants where so high a vacuum is not required, about 3 per cent. Power for power, therefore, the electrically driven auxiliaries are less economical. Taking into account, however, the radiation losses and drainage from the extra steam pipe in the former system and the extra cost of repairs to the steam plant as compared with, say, that for a low-tension A.C. motor, there appears

to be little to choose between the two on the point of running costs. The greater adaptability of the motor, especially to circulating pumps, points to the condenser pumps being electrically driven in future power houses.

Fig. 107 shows a longitudinal section, and Fig. 108 a cross-section of a Le Blanc rotary dry-air pump. This consists primarily of a reversed Pelton turbine wheel together with an

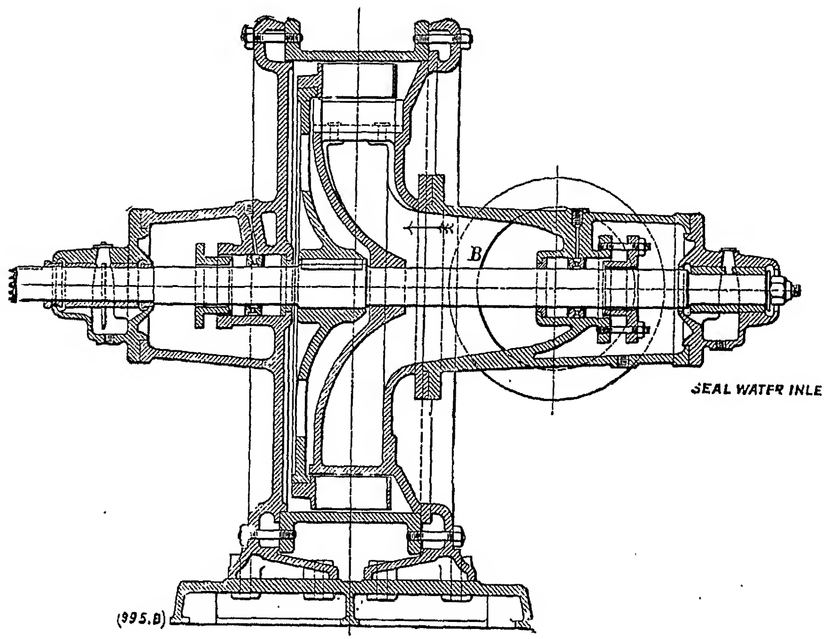


FIG. 107.

ejector. Sealing water is admitted through inlet A to the central chamber B, from which it passes through the post C. The water is then caught up by the blades D, and ejected into a discharge cone or nozzle at high velocity, and in thin sheets which meet the sides of the nozzle and form absolutely tight water pistons. These entrap the air and incondensible gases drawn over from the condenser through the suction inlet F, and carry them out against the atmospheric pressure. The same sealing water is used over and over again, since no appreciable

rise in temperature occurs in passing through the pump; or it may be passed through the condenser as circulating water. The

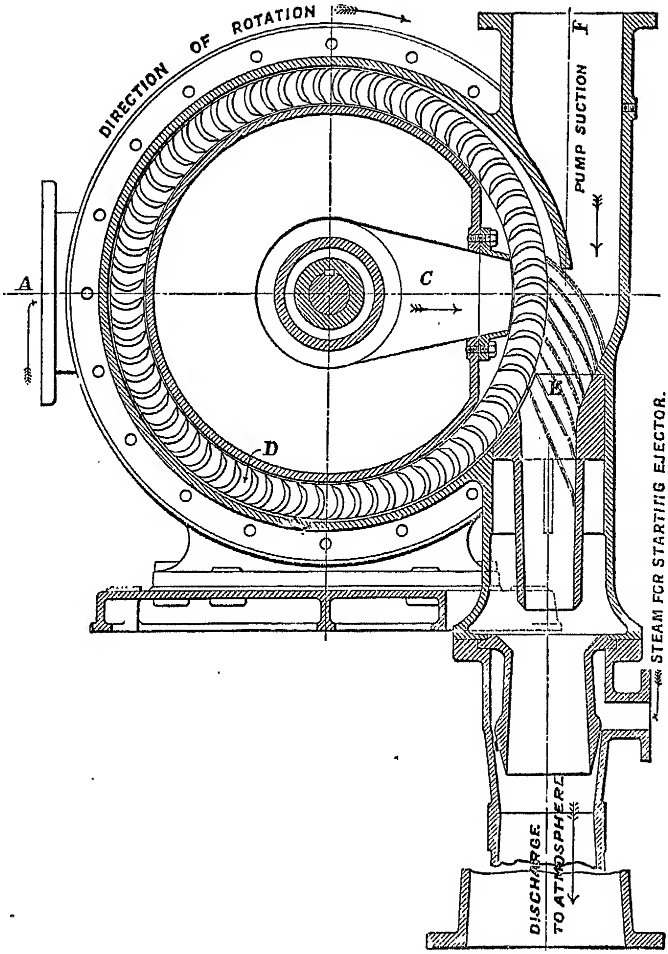


FIG. 108.

rotary air pump is driven at high speed and coupled direct to a motor, or, in some cases, to a steam turbine.

There are no reciprocating parts, valves, waste clearance spaces, or buckets, and the efficiency is high; moreover, but little attention and maintenance are needed. This type of pump

is particularly applicable to turbine plants, as it is able to attain a high percentage vacuum.

In a test conducted for the Author the following figures shown in Table No. LXX. were obtained :—

TABLE LXX.

CONDENSER TEST (BAR. 30·1″).

Steam condensed per hour.	Vacuum on condenser.	Energy consumption of pumps.	Load on plant.	Percentage of power absorbed by pumps.
lbs.	ins.	K.W.H.	K.W.	per cent.
19,900	28·5	40·08	1052	3·8
22,900	26·75	38·70	1302	2·9
24,500	26·25	40·56	1393	2·9
15,000	25·5	39·66	824	4·8
15,780	26·0	33·60	870	3·8
(Aver.) 19,476	26·6	38·52	1088	3·6

TABLE LXXI.

SIZES OF EDWARDS' THREE-THROW AIR PUMPS.

(Vacuum = 28″. Barometer = 30″. Inlet temperature = 60° F.)

Amount of steam in lbs. per hour.	No. of pump barrels.	Diameter.	Stroke.	Revolutions per minute.	B.H.P.	Approx. nett weight without motor.	Approximate dimensions.		
		ins.	ins.			cwts.	ft. ins.	ft. ins.	ft. ins.
7,500	3	8	8	150	3	40	5 0	7 8	1 11
10,500	3	9	9	150	$4\frac{1}{2}$	46	5 0	7 9	1 11
14,500	3	10	10	150	$6\frac{1}{2}$	56	5 9	8 3	1 11
21,000	3	12	10	150	9	75	6 2	9 0	2 4
25,000	3	12	12	150	11	78	6 9	9 0	2 4
29,000	3	14	10	150	12	96	6 11	9 9	2 6
33,000	3	14	12	145	14	100	6 11	9 9	2 6
42,000	3	16	12	140	18	107	6 11	11 0	2 10
53,000	3	18	12	140	22	116	6 11	12 0	3 0

The above Table, No. LXXI., gives the particulars of three-throw Edwards air pumps for working in connection with surface condensers. It is assumed the pumps will not have to deliver against a head, and that a 28-inch vacuum (barometer

at 30 inches) is to be maintained with circulating water at an inlet temperature of 60° Fahr. For a vacuum of only 26 inches (barometer 30 inches) the pumps would, of course, have to deal with increased quantities of steam and would run at a considerably higher speed. The motors must be capable of giving the stated B.H.P. continuously, and the speed should never exceed six times that of the air pump. The weights of the motors are not included in the table.

Circulating Pumps.—Table No. LXXII. sets out the sizes of some typical circulating pumps with the H.P. required per yard of head on the pump, including the equivalent loss of head due to pipe friction and bends.

TABLE LXXII.

CIRCULATING PUMPS.

Diameter of impellor (inches) .	21	24·5	27·5	31	34·5	39·5	43
Discharge per minute (gallons)	770	1100	1760	2200	2970	3740	4510
Revolutions per minute for stated head of 24 ft. . . .	540	460	420	370	330	290	270
H.P. required per yard of head	1·42	1·83	2·84	3·66	4·57	5·95	7·13
Nett weight (tons)	0·7	0·94	1·28	1·68	2·06	2·58	3·15
Approximate pre-war cost—							
Electrically driven . £	63	75	88	96	119	174	203
Steam driven . . £	80	85	110	122	142	170	195

The results of a test of a 5000 K.W. turbine are set out in Table No. LXXIII. and show the power required by auxiliaries.

TABLE LXXIII.

POWER REQUIRED BY CONDENSER AUXILIARIES.

(Results of test of 5000 K.W. turbine.)

Turbine load : K.W.	2713	3410	4758
Vacuum : inches	28·4	28·7	28·6
Barometer : inches	29·53	29·95	29·96
Auxiliaries—			
(i) Circulating pump : I.H.P.	69·1	69·1	69·1
(ii) Dry air pump : I.H.P.	24·3	23·2	23·8
(iii) Step bearing pump : I.H.P. . . .	6·4	5·8	5·6
(iv) Wet pump : E.H.P.	8·6	9·2	9·8

When reduced to the same units, the power requirements are seen to represent from 2·6 to 1·5 per cent. of the output of the turbine at the respective loads.

Summary on Condensers: Types Compared.—Simple or multiple jet condensers may be adopted with reciprocating engines, and offer a lower initial cost than surface condensers. Although jet condensers are initially cheaper and require less circulating water than surface condensers, it must be remembered that the condensed steam is rejected with the circulating water and that heat units, which might otherwise have been used for feed water purposes, are lost. In addition, the oil brought over from the engine has to be extracted before the water can be used again in the boilers. If surface condensers be used with reciprocating engines, then it is necessary (*a*) to include an exhaust separator between the engine and condenser, so as to remove much of the oil carried over by the exhaust, and prevent its deposit on the condenser tubes; and (*b*) to submit the air pump discharge water before it enters the hot well to some chemical treatment, as described in Chapter IV. These provisions are unnecessary with turbo-generators, and surface condensers have many advantages with this type of plant.

TABLE LXXIV.

COMPARATIVE DATA FOR CONDENSERS.

(Barometer 30″. Injection water 60° Fahr.)

Duty. Lbs. steam per hour.	Surface plants. Vacuum 28 ins.		Barometric plants. Vacuum 28¼ ins.	
	Approximate price. (Pre-war.)	Circulating water. Gallons per hour.	Approximate price. (Pre-war.)	Injection water. Gallons per hour.
	£		£	
5,000	425	19,800	350	15,960
9,000	550	32,400	460	28,800
16,000	750	57,600	600	51,600
25,000	1000	90,000	830	80,400
33,000	1225	120,000	1000	105,600
45,000	1625	162,000	1275	144,000
54,000	1850	195,000	1460	174,000

The comparative figures given in Table No. LXXIV. will be

of use to the designer. They indicate the pre-war costs of various sizes of jet barometric and surface condensers, together with the quantities of circulating water required in each case.

The barometric jet condenser may prove the most suitable in certain cases, but has necessarily to be erected away from the engine, thus involving a long and expensive pipe between the engine and the condenser, and a corresponding loss of vacuum at the engine due to pipe friction and air leakage. Moreover, the pumping costs are high, owing to the water having to be lifted to the condenser level. The condenser is placed at such a height that the injection water and condensed steam flow from the condenser against the atmospheric pressure by gravity, and the usual water extracting pump is replaced by a pipe from the bottom of the condenser to a small sealing tank which forms the barometric leg.

For small plants, especially where cooling towers are necessary, jet condensers either of the low level or barometric type may be adopted. For larger plants with reciprocating engines, either kind of condenser may be adopted to suit best the particular plant and locality; while for turbine plants and power houses of larger size, especially where there is a plentiful supply of circulating water, surface condensers have the advantage.

Materials Used in the Construction of Condensers.—The following notes on materials will be of use in specifying for condensers.

Cast iron to be well and cleanly cast from good grey-coloured, close-grained pig iron of such a mixture as to yield the best results in strength and toughness. A test bar 3 feet 6 inches in length and 2 inches by 1 inch cross-section when placed on bearings 3 feet apart should bear, without breaking, a load of 30 cwt. suspended from its centre, and with a deflection of not less than $\frac{5}{16}$ inch.

Tube plates, etc., for surface condensers to be of best rolled brass, containing 62 per cent. copper, 37 per cent. zinc, and 1 per cent. tin.

Tubes for surface condensers to be of solid drawn brass, containing 70 per cent. copper, 29 per cent. zinc, and 1 per cent. tin.

They are usually $\frac{3}{4}$-inch external diameter, and 0·048 inch in thickness.

Tubes should always be carefully tinned both inside and outside.

The following tests for tinning will be of use.

The samples, having been cleaned with alcohol or ether, are immersed for one minute in hydrochloric acid. They are then rinsed in clean water and immersed in sodium sulphide solution (specific gravity 1·142) for a period of 30 seconds, and again washed. They are then examined with a magnifying glass. The process is repeated several times, until blackening becomes clearly visible. The number of such operations required to produce this blackening is noted, and is taken to represent the measure of efficiency of the tinning.

Gun-metal parts for air pumps, etc., are usually made from a mixture of 88 per cent. copper, 10 per cent. tin, and 2 per cent. zinc.

Manganese bronze rods, etc., are usually made from a mixture having a tensile strength of 29 tons, and an elastic limit of 13·4 tons, and giving an elongation of 20 per cent. in a test length of 2 inches.

Tests of condenser bodies, etc., are usually made by subjecting them to an hydraulic pressure of 30 lbs., and motors and pumps are run under the usual conditions to ascertain power absorbed, temperature rise, etc.

Cooling Towers and Ponds.—In situations where an abundant natural supply of condensing water cannot be obtained from a large river or estuary, or where the cost of pumping such a supply would be prohibitive, it becomes necessary to resort to the use of cooling towers or ponds in order to make the maximum use of the more limited supplies actually available. The circulating water discharged from the condensers is cooled in the towers or pond and then used over again, its average temperature generally being higher than that of the injection water derived from a natural source of supply on account of the smaller quantity used per lb. of steam condensed. In addition to the initial supply of water to the condensing and cooling plant, a "make-up" supply must also be available to compensate for the permanent losses due to evaporation, etc.

Cooling Ponds.—Plain cooling ponds can only be considered practicable for quite small plants. A minimum allowance of 300 cubic feet of pond storage per H.P. is necessary, and a surface of not less than 100 square feet per H.P. These figures apply to plants running on an average for ten hours per diem, and under average conditions of atmospheric temperature and humidity.

The cooling efficiency of ponds is sometimes increased by the use of revolving nozzles to spray the water, or by a series of weirs, or bundles of brushwood, so as to break up the water and expose it to the air.

Cooling Towers.—Cooling towers are necessary for larger power houses where the conditions as to the supply of circulating water render cooling obligatory. There are three types of cooling tower, namely :—

(*a*) Natural draught open type.
(*b*) Natural draught chimney type.
(*c*) Forced draught chimney type.

The power required to run a forced draught tower is prohibitive and the natural draught chimney is the type most usually adopted. It requires more ground space than the forced draught tower, but less than the natural draught open type.

The natural draught chimney discharges the vapour at such a height—varying from 50 to 80 feet—as to obviate nuisance and rain. The level of the water inlet is usually about 25 feet from the tank water level.

Area Required.—The area required for natural draught towers is 1 square foot to each 20 lbs. of steam condensed. This figure will suffice for a general preliminary estimate or design, but must only be taken as very approximate, since the average temperature and humidity of the atmosphere in any particular locality have to be considered. The circulating water required is about 60 gallons per square foot of ground area, the water being cooled from 95° Fahr. to 75° Fahr. This may be taken as a standard for natural draught towers.

Efficiency of Natural Draught Towers.—The efficiency of natural draught cooling towers depends upon—

(*a*) The maximum temperature of the injection or circulating

water obtainable by a counter-current jet condenser allowing the water to be discharged at practically the vacuum temperature. (Other things have to be considered when selecting the type of condenser, *ubi supra.*)

(*b*) The design, which should be such that a minimum quantity of water is in circulation to deal with the heat units dispersed per unit of time, and should require only a minimum lift of water.

(*c*) The *effective* area of the cooling stack or shaft, which should be a maximum proportion of the total area covered by the tower.

Where the water supply is obtained from cooling towers, a condenser should be used in which the temperature of the discharge water approaches within 5 per cent. of the vacuum temperature. The rise in the temperature of the circulating water will then be 20° Fahr., corresponding to the employment of about 52 pounds of water per pound of steam condensed.

Cooling towers evaporate from 8 to 15 per cent. of the total water circulated in a run of about 10 hours, according to the atmospheric temperature and humidity. Local conditions of course differ, but for a hot climate, for example, with an average atmospheric temperature of 32° C. (89·8° Fahr.) and 85 per cent. average humidity, it is usual to specify a duty of so many gallons of water per hour, the water to be cooled from 54° C. (129·4° Fahr.) to 36° C. (97° Fahr.). Equivalent figures may be specified to suit a particular locality.

Fig. 109 contains a series of curves given by J. R. Bibbins in a paper read before the American Society of Mechanical Engineers, which show the vacua possible with varying conditions of condenser and with fixed cooling tower performance.

Modern air pumps—such as the Le Blanc—make it possible to operate condensers on small temperature differences of from 2° to 5° Fahr., with a reasonable injection or circulating water ratio. The smaller this temperature difference, the higher is the permissible maximum temperature of the circulating water at the inlet to the condenser and of the air to the cooling tower for any given conditions.

Thus for a 28-inch vacuum, 20° difference of temperature in

the condenser and 15° in the tower, the highest permissible temperature of the outside air is seen from the curves to be 65° Fahr. With warmer air the vacuum would fall.

Construction of Cooling Towers.—Cooling towers are sometimes constructed of a wooden framework with wood sheeting, and are fitted internally with distributing troughs and series of hurdles or laths which break up and spray the falling water. It is better practice to spend a greater initial sum, and to build a more permanent shell for the tower. This may either be of reinforced concrete or of brick, the former being rather better practice, especially in countries liable to severe frosts. The

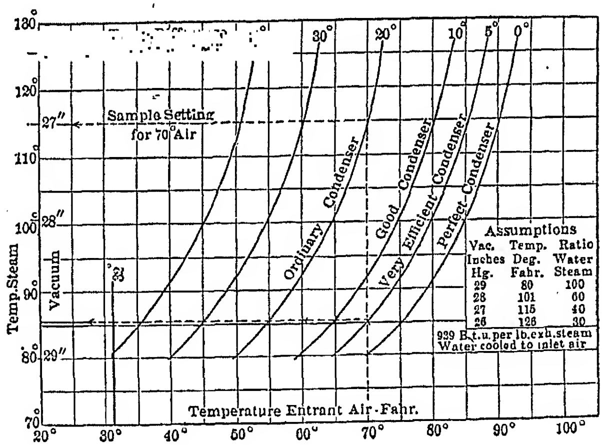
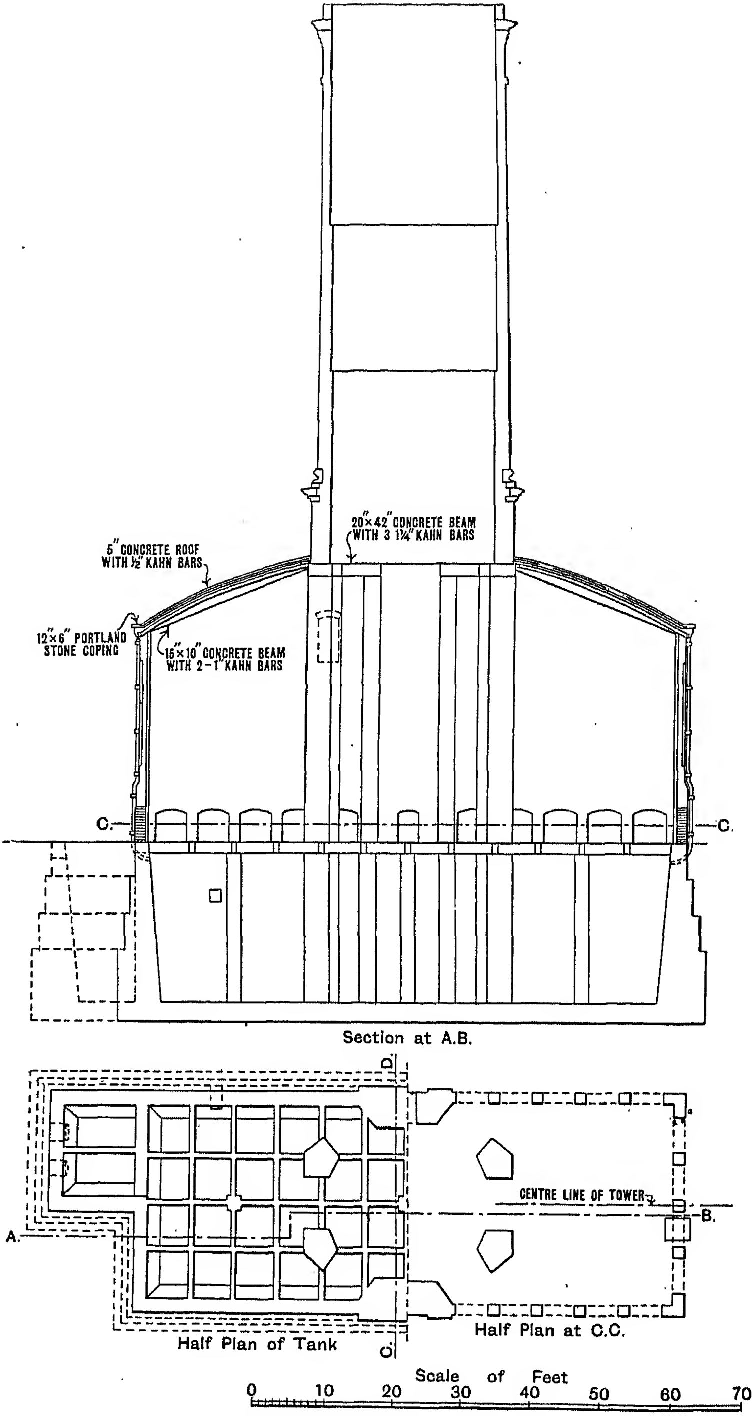


FIG. 109.

structure should be designed to withstand a wind pressure of 40 lbs. per square foot, and since it offers a very large surface, this must be carefully checked. Fig. 110 illustrates one of the large reinforced concrete towers built for the Author at Bahia Blanca.

The bottom openings admitting air to the tower should be fitted with louvres, to prevent the falling water from being splashed or blown out. All wood should be thoroughly seasoned and impregnated with a preservative compound, such as sideroleum, and weighed before and after treatment. Each cubic foot of timber should absorb not less than 8 to 10 lbs. of compound applied under a pressure of 100 lbs. per square inch.



20"×42" CONCRETE BEAM WITH 3 1¼" KAHN BARS
5" CONCRETE ROOF WITH ½" KAHN BARS
12"×6" PORTLAND STONE COPING
15"×10" CONCRETE BEAM WITH 2-1" KAHN BARS
C.
C.
Section at A.B.
D.
A.
CENTRE LINE OF TOWER
B.
C.
Half Plan of Tank
Half Plan at C.C.
Scale of Feet
0
10
20
30
40
50
60
70

FIG. 110.

The internal distributing troughs and cooling hurdles should be independent of the structure and easily renewable. Copper nails should be used, if nails are necessary; but, as a rule, in well-designed towers no nails are used. An access ladder is necessary to inspect the troughs and to adjust the flow of water in the distributing troughs.

The tank should be of concrete, mixed in the proportion of 27 cubic feet of stone and 13½ cubic feet of sand to 6½ cwt. of cement. The inside, after being rendered smooth with cement, can be lined with two coats of bitumastic solution. This soaks into the pores and prevents the concrete from sweating after it has thoroughly set. The bottom of the tank should be laid with a fall to one corner, and a small sump arranged at that point for emptying. Tanks have to be run out from time to time, so as to remove the impurities which will gather and concentrate at the bottom.

Steel cooling towers are also made both for natural and for forced draught, but the life of the plates is necessarily shorter than that of brick or concrete towers. From the Author's experience with them, a good deal of scraping and painting is necessary, and they cannot compare in durability with the brick or reinforced concrete tower.

TABLE LXXV.

NATURAL DRAUGHT CHIMNEY COOLING TOWERS.

Steam condensed per hour.	Circulating water per hour.	Ground space.		Total height.	Approximate foundations.		Approximate weight.	
		Length.	Width.		Excavation.	Concrete.	Dry.	Wet.
lbs.	gallons.	ft.	ft.	ft.	cub. yds.	cub. yds.	tons.	tons.
10,000	40,000	26	24	60	160	54	23·5	25·5
15,000	60,000	37	24	65	230	74	32·5	35·0
20,000	80,000	48	24	65	299	94	40·0	43·5
30,000	120,000	69	24	65	430	132	55·0	59·0
40,000	160,000	91	24	70	565	171	71·0	76·0
50,000	200,000	113	24	70	702	211	87·0	93·0
60,000	240,000	134	24	75	832	249	103·0	110·0
70,000	280,000	156	24	75	970	289	119·0	128·0
75,000	300,000	168	24	80	1040	310	129·0	139·0

The sizes, capacities and other leading particulars of natural draught chimney type cooling towers are set out in Table No. LXXV. (see p. 265).

The approximate cost of this type of tower before the war was £27 per 1000 lbs. of steam condensed per hour.

Similarly, Tables Nos. LXXVI. and LXXVII. give the sizes and other leading particulars of natural draught open type cooling towers.

TABLE LXXVI.

NATURAL DRAUGHT OPEN TYPE COOLER.

For medium cooling.

Capacity: water per hour.	Ground space.		Total height.	Approximate foundations for average conditions.		Approximate weight.
	Length.	Width.		Excavation.	Concrete.	
gallons.	ft.	ft.	ft.	cub. ft.	cub. ft.	tons.
2,000	13	15	20	880	660	2½
3,000	13	18	20	1050	700	3
4,000	13	21	20	1180	730	3¾
5,000	13	24	20	1320	770	4½
6,000	18	18	20	1400	880	5
7,000	18	20	20	1480	920	5½
8,000	18	21	20	1590	955	6
9,000	18	23	20	1660	980	6½
11,000	18	24	20	1760	1020	7½
13,000	18	30	20	1950	1060	8½
15,000	18	33	20	2120	1130	9¼
17,000	18	36	20	2300	1200	9¾
20,000	18	41	20	2500	1270	11
22,000	23	32	20	2650	1410	11
24,000	23	34	20	2800	1490	11½
26,000	23	36	20	3000	1550	12¼
28,000	23	39	20	3200	1630	13¼
30,000	23	41	20	3350	1700	14
35,000	23	46	20	3550	1800	16
40,000	23	52	20	4100	1920	18
45,000	23	57	20	4600	2050	20
50,000	23	62	20	4950	2200	22
55,000	23	68	20	5300	2330	24½
60,000	23	73	20	5650	2620	26½
65,000	23	79	20	6000	2760	28½
70,000	23	84	20	6400	2900	30½
75,000	23	90	20	6700	3040	32½
80,000	23	95	20	7100	3200	34½
90,000	23	106	20	7400	3320	36½
100,000	23	117	20	8200	3550	38½

TABLE LXXVII.

NATURAL DRAUGHT OPEN TYPE COOLER.

For very low cooling down to air temperature with low humidity.

Capacity: water per hour.	Ground space.		Total height.	Approximate foundations for average conditions.		Approximate weight.
	Length.	Width.		Excavation.	Concrete.	
gallons.	ft.	ft.	ft.	cub. ft.	cub. ft.	tons.
400	13	13	20	700	630	$2\frac{1}{4}$
800	13	16	20	885	690	$2\frac{3}{4}$
1,200	13	20	20	1060	740	$3\frac{1}{2}$
1,600	13	24	20	1240	795	$4\frac{1}{2}$
2,000	13	28	20	1410	810	5
3,000	13	38	20	1770	890	7
4,000	13	47	20	2120	960	$8\frac{3}{4}$
5,000	18	33	20	2120	1060	$9\frac{1}{4}$
6,000	18	38	20	2300	1160	$10\frac{1}{4}$
7,000	18	43	20	2470	1240	$11\frac{1}{2}$
8,000	18	47	20	2550	1300	13
9,000	18	52	20	2700	1350	$14\frac{1}{2}$
10,000	18	57	20	2830	1410	16
11,000	23	44	20	3200	1590	16
12,000	23	47	20	3350	1700	17
13,000	23	51	20	3530	1770	18

Humidity.—The efficiency and size of cooling towers depend on the average humidity of the atmosphere of the district where the plant is to be installed. To enable the designer to ascertain this, the following formula may be used in conjunction with the data given in Table No. LXXVIII., the only instruments required being wet and dry bulb thermometers and a barometer.

Let F denote the vapour pressure in inches of mercury corresponding to the temperature T of the dry bulb (in degrees Fahrenheit), and let F′ be the vapour pressure corresponding to the reading T′ of the wet bulb. Also let L denote the height of the barometer in inches of mercury. Then the relative humidity (F′ ÷ F) is given by the following approximate formula due to Apjohn:—

$$F = F' - \frac{L(T - T')}{2610}.$$

The values of the vapour pressure at different temperatures are set out in Table No. LXXVIII. :—

TABLE LXXVIII.

VAPOUR PRESSURES FOR DETERMINING RELATIVE HUMIDITY.

Temperatures Centigrade.	Vapour pressures. Mm. of mercury.	Vapour pressures. Ins. of mercury.	Temperatures Fahrenheit.
0	4·58	0·180	32
5	6·54	0·257	41
10	9·21	0·363	50
15	12·79	0·504	59
20	17 54	0·691	68
25	23·76	0·935	77
30	31·83	1·253	86
35	42·19	1·661	95
40	55·34	2·179	104
45	71·90	2·831	113
50	92·54	3·643	122
55	118·11	4·650	131
60	149·46	5·884	140
65	187·64	7·387	149
70	233·79	9·204	158
75	289·32	11·390	167
80	355·47	13·995	176

CHAPTER VIII

GAS ENGINES AND GAS PRODUCERS: OIL ENGINES

The two classes of internal combustion engine available for use in power houses of a small or moderate capacity are the gas engine and the oil engine. The manufacture of these engines is now a well-established industry of considerable magnitude and has been marked by constant progress as regards the design and reliability of this type of plant.

From the point of view of thermal economy, the internal combustion engine possesses a substantial advantage over the best steam power plant; at full load, thermal efficiencies of 30 per cent. and over are obtainable as compared with the highest recorded figure of 18 per cent. for steam plants and the more usual figures of 9 to 12 per cent. There are other considerations, however, which serve to impose a limitation to the use of present types of internal combustion engines in large power houses. In the first place, the largest units hitherto in successful commercial operation are relatively quite small in comparison with large modern steam turbine units. In the next place, the speed of large engines is necessarily low, and on account of their size and weight they occupy considerable space and require very substantial foundations. In the last place, their overload capacity is inferior to that of steam plant. Having regard to these factors and to the multiplication of units in a power house of any magnitude, the internal combustion engine as at present developed is only economical from the standpoints of capital costs and running costs in stations of small or moderate capacity.

The gas engine has been more extensively used in power houses than the oil engine, and it will be convenient to devote separate consideration to these two classes of prime mover.

One of the first questions confronting the designer of a gas

engine station is the supply of a suitable fuel at the lowest possible cost. It is therefore necessary to deal briefly with the power gases generally used in gas engines and with the fuels and types of gas-making plant required for their manufacture.

Power Gases.—A variety of gaseous fuels can be economically employed for the operation of gas engine power houses. In particular cases, use can be made of the waste or surplus gases from blast furnaces or coke ovens for generating a supply of electrical energy for the works and sometimes for the surrounding districts. In the generality of cases, however, the power house has to be equipped with gas producer plant, and the type to be installed will depend upon considerations such as the size of the power house, the cost and character of the solid fuel available, and whether the gaseous fuel is needed for other works requirements as well as for the gas engines.

Information regarding the approximate compositions and other particulars of the power gases commercially available is set out in Table No. LXXIX.

Blast furnace gas is an excellent fuel, and its low content of hydrogen renders it specially suitable for engines with high compressions. The gas, however, is very dusty and requires to be mechanically cleaned, cooled, and deprived of free moisture before being used in the engines.

Producer gas, whether obtained from anthracite, coke, bituminous coal or slack, or from lignite, wood or other carbonaceous material, is generally found to be the cheapest and best fuel for gas engines. Suction gas is usually employed when the engines are of small or moderate size, but for the largest engines producers of the pressure type or suction-pressure type are most suitable. The amount of dust, moisture, and tarry products in producer gas varies according to the character of the fuel employed and with the method of manufacture. In all cases, it is necessary for the gas to be cooled, cleaned, and dried before it is supplied to the engine, and for its content of tar to be reduced to very small proportions, not exceeding say 0·03 grains per cubic foot. When use is made of bituminous coals or other fuel rich in volatile, the efficient extraction of tarry products from the producer gas is a matter needing careful attention.

TABLE LXXIX.

COMMERCIAL POWER GASES: APPROXIMATE DATA.

Data.	Blast furnace gas.	Suction producer gas.		Pressure producer gas. (Bituminous coal.)		Blue water gas.	Coke oven gas.	Coal (town) gas.
		Anthracite fuel.	Coke fuel.	Ammonia recovery producer.	Non-recovery producer.			
Approximate constitution (percentage by volume):								
H_2	1	15·6	14	26	17	52	52	43
CO	28	20	25	11	23	42	7·5	10
CO_2	12	6	6·4	16·9	5	4	5·5	—
CH_4	—	1·1	—	2·7	3	1	21·5	33
C_nH_{2n}	—	—	—	—	—	—	1·5	4
N_2	59	57·3	54·6	43·4	52	3	2	10
Approximate volume of air required for combustion of 1 volume of gas	0·69	0·85	0·93	1·14	1·24	2·29	3·79	5·27
Mean calorific value (B.Th.U.)								
Per cubic foot of gas	95	124	124	140	157	300	415	560
Per cubic foot of mixture with air for complete combustion	56	67	64	65	70	91	86	89

Water-gas is not such a desirable fuel for gas engines owing to its high percentage of hydrogen and to the danger of back-firing or pre-ignition if the compression is carried beyond a certain critical point. The gas becomes more suitable when carburetted, i.e. when enriched with gas oil, but this process of course renders the fuel more costly.

Coke-oven gas is also a good fuel for gas engines although, like water-gas, it contains a considerable percentage of hydrogen. The crude gas from the coke-ovens contains tar, sulphur, and other impurities, and requires much purification before being supplied to the engines.

Ordinary illuminating gas (town gas) can be used direct from the mains without needing further treatment, and finds an application in small gas-engine installations. The cost of this gas, however, is usually too high to permit of its use for general power purposes.

The approximate compositions and calorific values of the principal raw fuels available for the manufacture of producer gas are given in Table No. LXXX.

TABLE LXXX.

APPROXIMATE DATA FOR SOLID FUELS.

Class of fuel.	Approximate composition (principal constituents only).			Approximate calorific value per lb. of combustible.
	Carbon.	Hydrogen.	Oxygen.	
	per cent.	per cent.	per cent.	B.Th.U.
Anthracites	90 to 95	2·5	3·0	14,400 to 16,200
Bituminous coals	75 ,, 90	4·5 to 5·5	5·0 to 15·0	14,400 ,, 16,200
Brown coals and lignites	60 ,, 75	5·0	20 ,, 35	10,800 ,, 12,600
Wood	50	6·0	43·5	7200 ,, 7700

The above figures relate to ash-free, dry fuels.

The amount of free and fixed mineral matter present in the different classes of coal varies very widely, and in the case of the cheaper qualities of bituminous slack may range from 30 per cent. upwards. The presence of a high percentage of ash may give rise to serious trouble through clinkering, and when a fairly clean fuel is available at a reasonable cost, it is open to question whether any economy is to be gained by resorting to the use of a more dirty although cheaper fuel.

With regard to coke fuel for producers, it must be remembered that this contains the whole of the ash present in the coal from which it was made. On the other hand it contains but little volatile and therefore yields a gas which is practically free from tarry products. The average calorific value of good quality coke from gas works or coke ovens ranges from 11,000 to 12,000 B.Th.U. per lb. as fired.

The calorific value of the fuel employed should be determined by a calorimeter. If, however, the percentage composition of the fuel is known, its calorific value can be ascertained with close approximation from the following formula :—

$$\text{B.Th.U. per lb. of combustible} = 146C + 620\left(H - \frac{O}{8}\right) + 40S$$

where C, H, O, and S represent the percentages of carbon, hydrogen, oxygen, and sulphur respectively in the dry fuel. This formula must be used with caution because in the case of coals containing upwards of 7 per cent. of oxygen, the calculated and calorimetric values usually show an increasing difference.

Standard for Gas Measurement.—The volume of power gas measured at any temperature should be reduced to the equivalent figure at a standard temperature and atmospheric pressure, corrected for the effect of moisture in the gas. The standard recommended is the equivalent volume of the gas when saturated with moisture at normal atmospheric pressure and at a temperature of 60° Fahr. To reduce the volume at any other temperature to this standard, the reading should be multiplied by the factor—

$$\frac{459{\cdot}4 + 60}{459{\cdot}4 + T} \times \frac{B - (29{\cdot}92 - V)}{29{\cdot}4}$$

where B = height of barometer in inches at 32° Fahr.,
T = temperature in degrees Fahr. of gas at meter,
V = vacuum in inches of mercury corresponding to temperature T.

Gas Producers.—Producers of the suction type are usually employed for the smaller sizes of gas engine, the air necessary for the combustion of the fuel in the producer furnace being automatically drawn in at each suction stroke of the engine. The demand upon the engine therefore regulates the generation of the gas. In the case of the larger sizes of gas engines, producers of the pressure type are more suitable. In these plants, the air supply is forced through the furnace by means of blowers after being previously heated by passage through an economizer.

There are many excellent makes of producers available to the designer, in standard sizes ranging up to 1000 B.H.P.

capacity and over. It is outside the scope of this book to deal with the different details of various designs, and it will suffice to give, by way of example, a short description of a producer of each of the types previously mentioned.

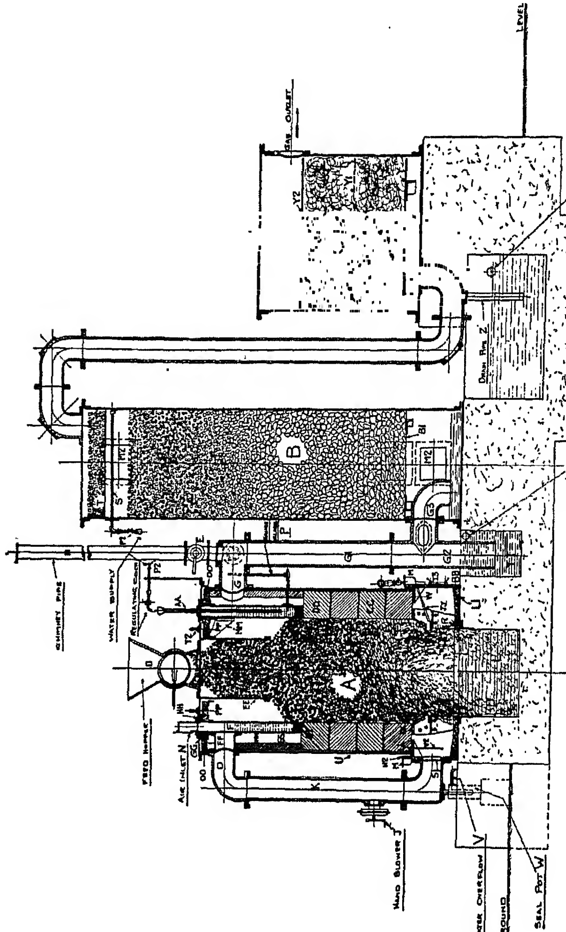


FIG. 111.

Suction Gas Producers.—An illustration of a standard type of suction gas producer as made by the Power Gas Corporation, Ltd., of Stockton, England; in sizes up to 500 B.H.P. capacity is given in Fig. 111. The plant consists of a furnace A in which the anthracite, coke, or charcoal is burnt and gasified by

a current of air mixed with steam, a scrubber B filled with coke in which the gas is cooled and cleaned, and a drier C for removing moisture and traces of dust or other particles in suspension in the gas, the latter then passing to the engine. The furnace is lined with firebrick and has an external jacket U in which the air supply is preheated, the air entering at an inlet N and passing to a vertical pipe K leading to the grate. The steam is supplied from an internal vaporizer F at the top of the furnace, auxiliary drip cups M at the bottom of the furnace casing being provided for starting up purposes. The coke filling in the scrubber B is kept thoroughly wet by means of a water spray S. The charging-hopper of the furnace is constructed so as to prevent a leakage of air into the gas generator. When the gas plant is being brought into operation prior to the starting of the engine, the inlet N is closed and the air supply to the furnace is drawn through an inlet on a hand-blowing fan J.

In other types of suction producers, such as those manufactured by the National Gas Engine Co. of Ashton-under-Lyne, England, the steam supply is derived from an external vaporizer through which the furnace gases pass on their way to the scrubber, this vaporizer also serving as a preheater for the air supply to the grate. The water is continually fed on to the surface of the vaporizer, and the supply can be adjusted so that all the water passing in is evaporated. In this way, the proportion of steam in the air supply to the furnace can be controlled as desired.

Table No. LXXXI. gives an indication of the space required for suction gas plant of different sizes.

The total quantity of water required for circulating through the scrubber and for raising steam for the air supply amounts to from 1¼ to 1½ gallons per B.H.P. hour when anthracite, coke, or charcoal is employed. With fuels such as bituminous coal or waste wood, which yield tarry products, the total water consumption is somewhat greater amounting to about 4 gallons per B.H.P. hour.

The thermal efficiency of a well-designed suction gas producer operated under good working conditions is between 70 and 80 per cent., and with proper attention and control a figure

of 75 per cent. should be realized. The stand-by losses amount to from 1 to 3 per cent. of the fuel consumption at full load.

TABLE LXXXI.

SPACE REQUIRED FOR NATIONAL SUCTION GAS PLANT.

Size. (Maximum engine B.H.P. for 10 hours with anthracite fuel.)	Space required for working plant.						Weight.
	Ground space.				Headway.		
	ft.	ins.	ft.	ins.	ft.	ins.	cwts.
40 to 50	12	0	11	0	13	0	62
55 ,, 60	13	0	13	0	13	0	73
65 ,, 90	14	6	13	6	15	0	88
95 ,, 110	16	0	14	6	15	0	114
115 ,, 140	18	0	15	0	16	0	190
145 ,, 170	18	0	16	0	18	0	270
175 ,, 220	19	0	18	0	18	0	292
225 ,, 280	20	0	22	0	18	0	340
285 ,, 340	22	0	24	0	18	0	410
345 ,, 450	24	0	24	0	18	0	535
455 ,, 500	24	0	36	0	20	0	630

Pressure Producers.—Producers of large size, having gasification capacities ranging up to 30 tons of coal per 24 hours, are operated on the pressure system, a fan or blower giving a pressure of from 3 to 6 inches of water (according to the depth of fuel in the furnace) being employed to maintain the draught. There are numerous designs of such producers, and, as in the case of suction gas plants, the sensible heat in the gas issuing from the furnace is utilized for preheating the air supply and for vaporizing the water required in the blast.

Mechanical grates have been successfully adapted to large producers, and although they add to the capital cost, the advantages attaching to their use require careful consideration when designing a gas engine power house. These grates not only effect the automatic discharge of the ashes and reduce the tendency to clinker, but also break up the fuel bed and thus maintain a uniform resistance to the passage of the blast. Apart from economies in labour, mechanical producers have a further advantage in that coals of low quality with a high percentage of ash can be used without serious drawbacks.

A diagrammatic illustration of a modern pressure producer with ammonia recovery plant is shown in Fig. 112.

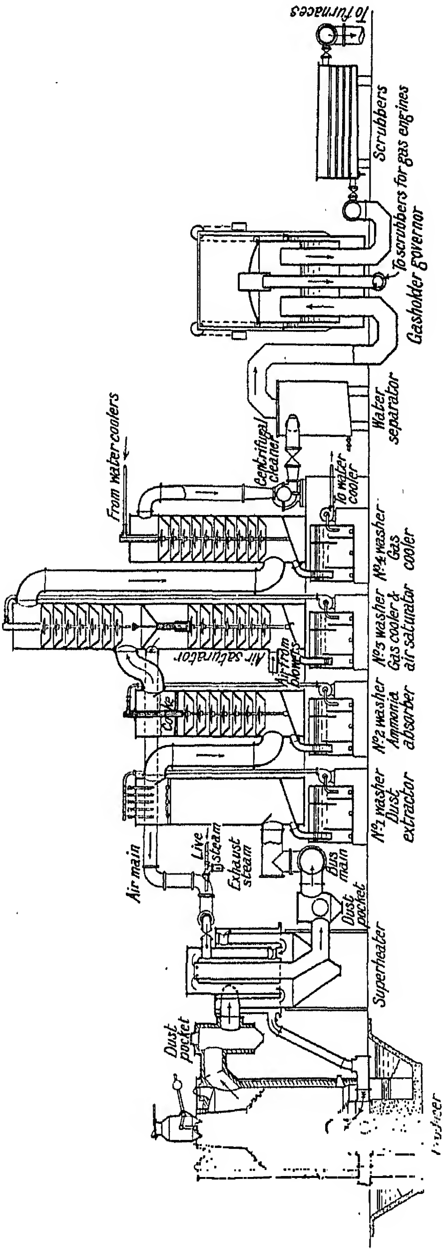

To furnaces
Scrubbers
To scrubbers for gas engines
Gasholder governor
Water separator
Centrifugal cleaner
From water coolers
To water cooler
No. 4 washer
Gas cooler
No. 3 washer
Gas cooler & air saturator
Air saturator
Air from blowers
Coke
No. 2 washer
Ammonia absorber
No. 1 washer
Dust extractor
Air main
Live steam
Exhaust steam
Gas main
Dust pocket
Superheater
Dust pocket

FIG. 112.

Ammonia Recovery Plant.—The possibility of recovering a valuable by-product such as ammonia from the coal used in the gas producer section of a power house presents obvious attractions. As a matter of fact, however, the designer is confronted with a question of considerable complexity when determining whether or not it will be worth while to install ammonia recovery plant.

In the first place, the recovery plant occupies considerable ground space and adds substantially to the cost of the power house. Whereas the larger sizes of suction producers could be purchased before the war at a cost of about £0·14 to £0·21 per ton of fuel maximum capacity per annum, the cost of a large recovery producer plant with the necessary boilers ranged from £0·7 to £0·9 per ton of coal maximum capacity per annum.

In the next place, the thermal efficiency of the gas-making operation is substantially reduced by adopting ammonia recovery conditions. To secure the maximum yield of ammonia, the quantity of steam employed in the air blast must be sufficient to saturate the air at a temperature of about 85° C., and the air and steam must be further heated to a temperature of from 180° C. to 230° C. before admission to the fuel in the producer. In practice, from $2\frac{1}{2}$ to $2\frac{3}{4}$ tons of low-pressure steam are required in the blast per ton of coal gasified, and of this quantity from 1 to $1\frac{1}{4}$ tons can be raised by means of the sensible heat of the gas leaving the producer, so that a nett balance of $1\frac{1}{2}$ tons has to be supplied from external sources. Under these conditions of operation, the thermal efficiency even in the most favourable circumstances is only between 50 and 60 per cent. as compared with a figure of say 75 per cent. in the case of non-recovery producers.

In the last place, considerable extra labour is required and substantial costs are incurred in operating recovery producer plant. About 1 ton of sulphuric acid is required for each ton of sulphate of ammonia obtained, and the cost of this acid delivered at the plant is therefore an important item. Under pre-war conditions in Great Britain, the average cost of recovering the sulphate and of preparing a product packed for the market amounted to from £2·5 to £3 per ton of sulphate. These figures

only apply to large plants where sulphuric acid was available at a cost of 25s. to 30s. per ton; they include the cost of the acid, labour, repairs, packing, and capital charges. Similarly, the costs of gasification, exclusive of sulphate recovery, but inclusive of steam raising ranged from about 3s. 6d. per ton of coal apart from capital charges.

From the above observations, it is apparent that careful attention must be given to the cost and nitrogen content of the fuel available, the rates of wages prevailing at the location of the power house, the proximity or otherwise of a market for the sulphate of ammonia, and the average selling price of the latter. From 65 to 70 per cent. of the nitrogen content of the coal is recoverable as ammonia, and a ton of bituminous coal containing 1·3 per cent. of nitrogen will yield about 95 lb. of sulphate of ammonia. A variation of 0·1 in the percentage of nitrogen present in the coal affects the yield of sulphate to the extent of from 7 to 7·5 lbs. of sulphate per ton of coal.

In cases where ample ground space is available, the economy or otherwise of installing ammonia recovery plant is broadly dependent upon the following factors:—

(*a*) The increased working costs and capital charges incurred with recovery gas producers.

(*b*) The cost of the larger thermal losses in the gas making and recovery operations. Owing to the lower thermal efficiency of the recovery process consequent upon the large quantity of steam required, the total fuel consumption may be from 40 to 50 per cent. greater than with non-recovery plant for the same output of power.

(*c*) The probable revenue to be derived from the sale of the sulphate of ammonia. This item is always characterized by some uncertainty owing to the continual fluctuations in the market price of the product.

(*d*) The size and plant load factor of the power house.

The results of experience before the war indicated that it was generally only worth while adopting recovery conditions with plants having a demand of 1500 B.H.P. and upwards, and then only with load factors of say 25 per cent. and over. In this connection it is to be noted that uniform working is

desirable, and that the working of recovery producers under fluctuating conditions of load is detrimental both to the yield of ammonia and also to the quality of the power gas.

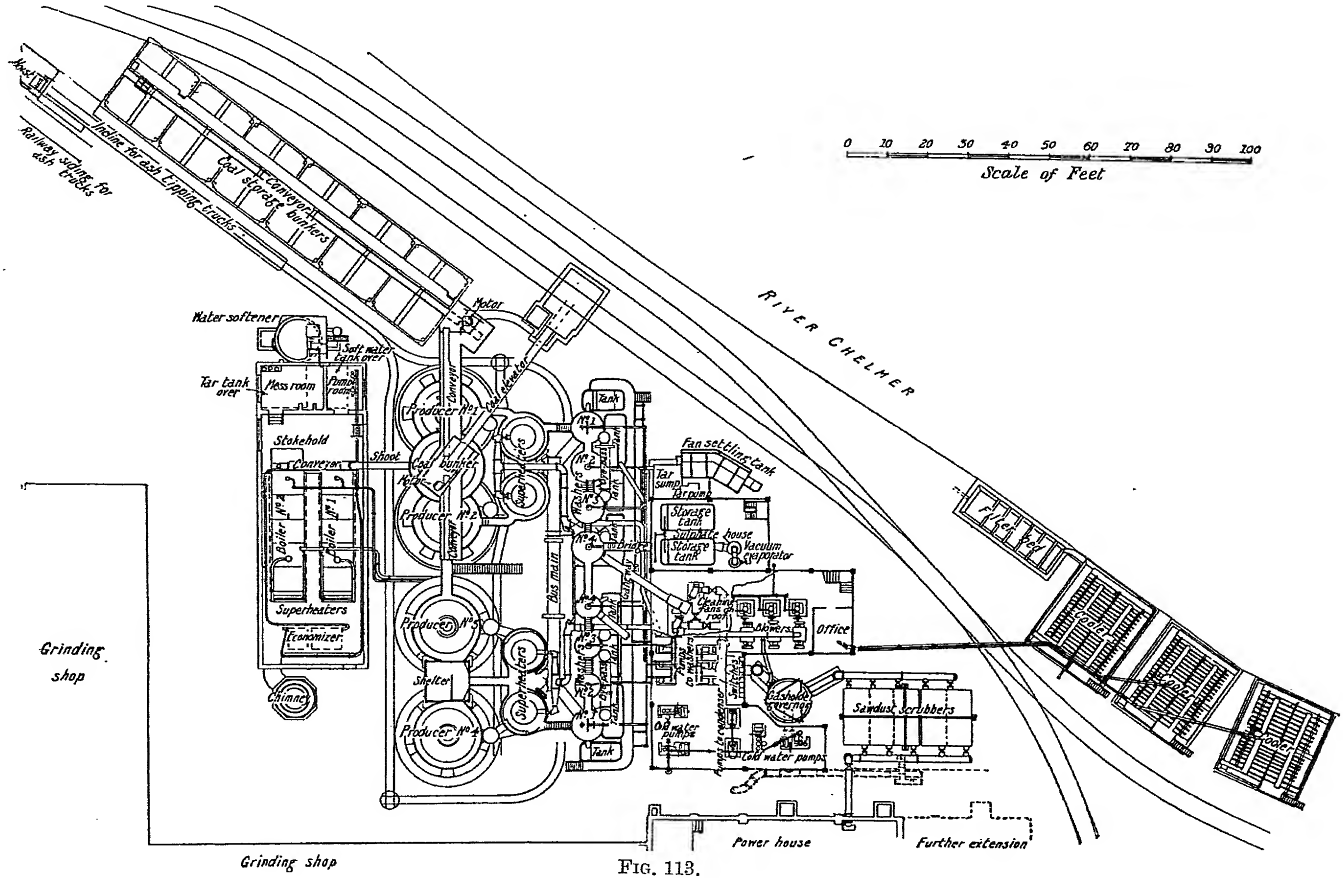
Fig. 113 illustrates the lay-out of a recovery producer installation at the works of the Hoffmann Manufacturing Co., Chelmsford, England, which the Author has been permitted to reproduce from a paper read by Mr. W. H. Patchell in December, 1919, before the Institution of Electrical Engineers, London. The installation consists of four "Lymn" producers (as made by the Power Gas Corporation, Ltd.) having a total capacity of 60 tons of coal per day, with superheaters for the steam-air blast, gas washers and coolers, ammonia absorbers, a gasholder governor and sawdust scrubbers, as shown diagrammatically in Fig. 112. The producer gas is utilized in part in gas engine generators, and in part for heating metallurgical furnaces. The installation of Lancashire boilers shown in Fig. 113 is used in conjunction with exhaust boilers fitted to the gas engines for raising the steam required for the recovery producer plant and for heating and other purposes in the works. The Lancashire boilers are fired partly with the tar recovered as a by-product from the gas plant and partly with coal. A summary of the working results is given later.

Regulations for Producer Plants.—The following extracts from the Regulations of the National Board of Underwriters will be useful in connection with the installation of producer gas plants.

(*a*) All pressure systems must be located in a special building approved for the purpose, and at such a distance from other buildings as not to constitute a danger.

(*b*) The smoke and vent pipe shall, where practicable, be carried above the roof of the building in which the apparatus is contained, and shall not pass through floors, roofs, or partitions, and shall end at least 10 feet from any wall.

(*c*) When the plant is not in operation, the connection between the producer and scrubber must be closed, and that between the producer and vent pipe opened so that the products of combustion may be carried into the atmosphere. This must



River Chelmer
Scale of Feet
0 10 20 30 40 50 60 70 80 90 100
Hoist
Railway siding for ash trucks
Incline for ash tipping trucks
Conveyor
Coal storage bunkers
Motor
Coal elevator
Water softener
Soft water tank over
Tar tank over
Mess room
Pump room
Stokehold
Conveyor
Shoot
Boiler No. 1
Boiler No. 2
Superheaters
Economizer
Chimney
Producer No. 1
Producer No. 2
Producer No. 3
Producer No. 4
Coal bunker
Conveyor
Shelter
Superheaters
Bus main
Washers
Tank
Fan settling tank
Tar sump
Tar pump
Storage tank
Sulphate house
Vacuum evaporator
Cleaning fans room
Blowers
Office
Pumps to washers
Switches
Pumps to condenser
Cold water pumps
Gasholder governor
Sawdust scrubbers
Filter bed
Cooler
Power house
Further extension
Grinding shop

FIG. 113.

be accomplished by a mechanical arrangement which will prevent one operation without the other.

(*d*) Before undertaking repairs which involve opening the gas passages to the air, the producer fire must be drawn and quenched, and all combustible gases blown out of the apparatus through the vent pipe.

(*e*) The opening for admission of fuel shall be provided with some charging device so that no considerable quantity of air can be admitted while charging the producer.

Gas Engines.—Gas engines are constructed to operate on the Otto or 4-cycle system whereby each single-acting cylinder gives one impulse stroke during two revolutions of the crank shaft, or upon the 2-cycle system with an impulse stroke per revolution of the crank shaft.

In engines of the 4-cycle type, the explosive mixture is ignited at the beginning of the impulse stroke, the return stroke serving to drive out the waste or exhaust products. A further charge of air and gas is drawn into the cylinder during the third stroke, the fourth (or second return) stroke compressing the charge ready for ignition. The crank shaft of single cylinder engines has an uneven angular velocity, and in order to minimise this cyclic irregularity use is made of two or more single-acting cylinders each coupled to a separate crank, or of double-acting cylinders to each crank arranged in single or double tandem form.

In engines of the 2-cycle type, the larger sizes of which usually have double-acting cylinders, the exhaust valves are opened at the end of each impulse stroke and the waste gases expelled by a forced or induced draught of air and the cylinder scavenged. The cylinder then receives the next charge which is compressed during the return stroke ready for ignition.

For detailed information regarding the development and design of modern types of gas engines the designer must consult the standard works on the subject. The Author is primarily concerned with the adaptation of gas engine prime movers to power house design, and the salient particulars of interest in this connection are dealt with below.

Cyclic Irregularity.—When gas engines are to be employed

for driving electrical generators, and especially alternators required to be run in parallel, smooth running is of great importance, and the degree of cyclic irregularity is therefore a factor to be considered in selecting a suitable type of engine.

Some useful curves were given in 1909 by Andrews and Porter ("Journal, Institution of Electrical Engineers," Vol. 43), which the author is permitted to reproduce in Figs. 114 and 115. The curves in these figures are based upon engine units of 750 B.H.P.

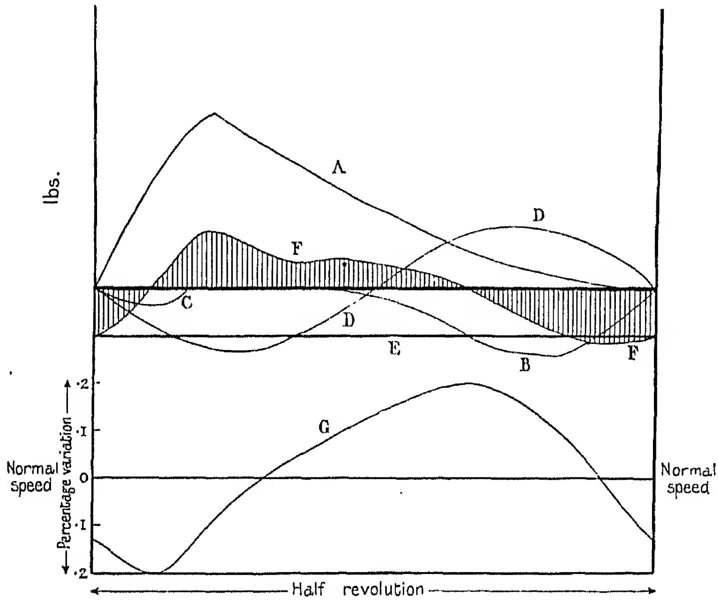
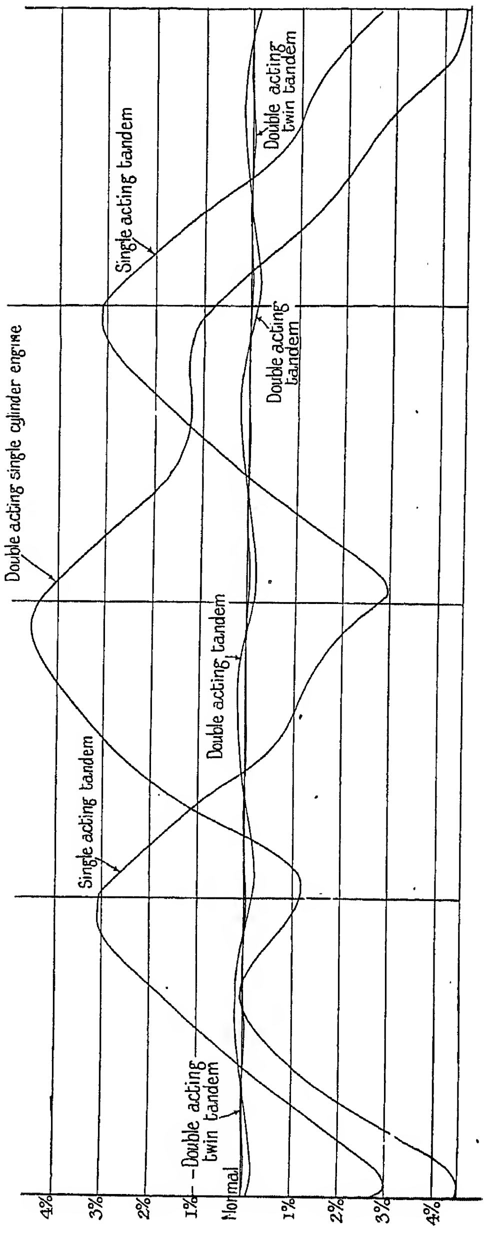


FIG. 114.

In Fig. 114 which relates to a double-acting single tandem engine, curve A shows the positive pressure in lbs. upon the crank pin throughout the impulse stroke due to the expansion of the gases. The connecting rod is assumed to be of infinite length. Curve B shows the negative pressure due to the compression throughout the compression stroke, and curve C shows the back pressure due to the effort prior to opening the exhaust valve. Curve D shows the positive and negative pressures due to inertia of moving parts, and curve E represents the negative



Single acting tandem
Double acting twin tandem
Double acting single cylinder engine
Double acting tandem
Double acting tandem
Single acting tandem
Double acting twin tandem
4%
3%
2%
1%
Normal
1%
2%
3%
4%

FIG. 115.

pressure resulting from the external load plus the engine friction. Curve F gives the resultant fluctuation of crank effort due to the above forces. The area above zero line represents the energy put into the fly-wheel, and that below the zero line the energy given out by the fly-wheel, the algebraic sum of which is, of course, zero. Curve G shows the variation of angular velocity throughout the stroke, and was deduced from curve F by the formula—

$$\text{Fluctuation of energy} = \frac{I}{G} QW^2,$$

where W = normal angular velocity in radians per second,
Q = percentage fluctuation of speed allowed,
I = moment of inertia of fly-wheel.

Fig. 115 illustrates graphically the percentage speed variation throughout each cycle of engines of different types fitted with fly-wheels of a given moment of inertia. The speed curves, which are constructed on the basis of Fig. 114, relate to 750 B.H.P. engines with a fly-wheel constructed for a tandem double-acting engine having a speed variation of $\frac{1}{250}$.

Horizontal Gas Engines.—Gas engines of the larger sizes are more generally of the horizontal type for which various advantages are claimed, such as accessibility to all working parts for inspection, cleaning and repairs, and the smaller head-room required.

Fig. 116 shows a longitudinal cross-section of a horizontal engine manufactured by Messrs. Galloways, Ltd., of Manchester, England. These engines are of the double acting 4-cycle type with cylinders arranged either in single or twin tandem form.

The engines embody some important features, which have been arrived at as the result of long experience and study, particularly in the design of the cylinders, in which internal stresses due to casting and stresses due to expansion in working are eliminated. The cylinder body is cast in two parts, bolted together circumferentially and fitted over a liner. The water jacket is enclosed by a rolled steel band, which is rubber jointed to the cylinder castings, so that relative motion due to unequal expansion is permitted without causing stress. The jacket can

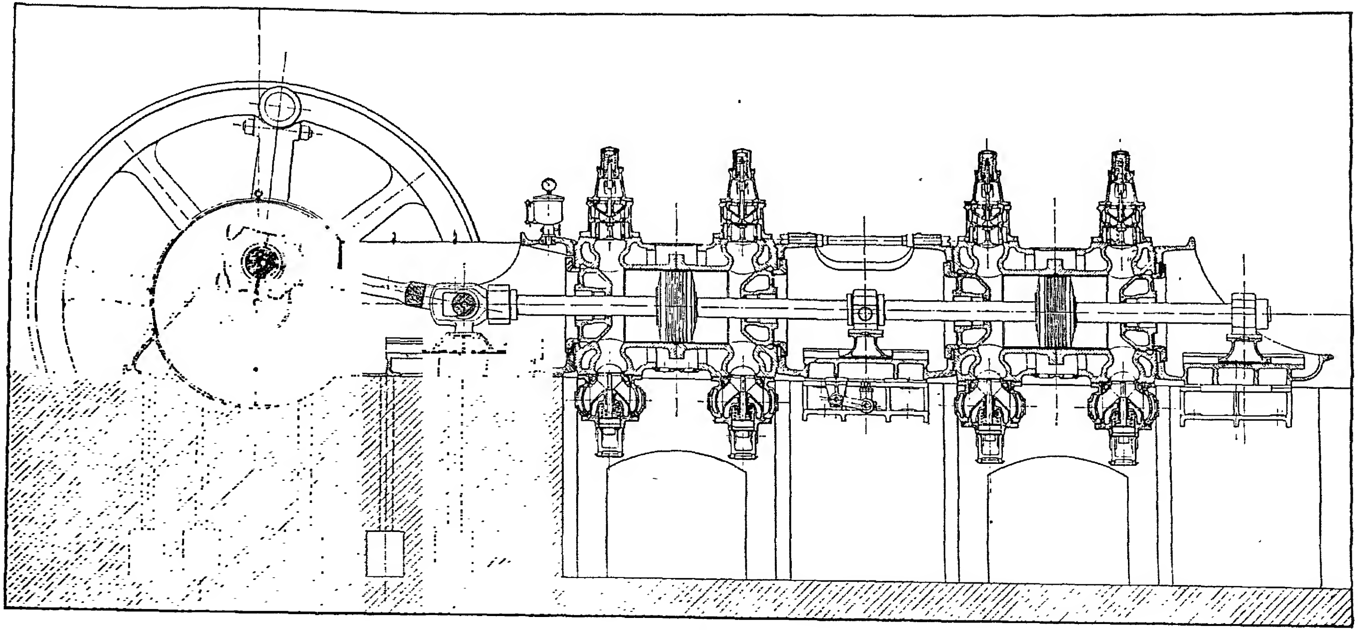


Fig. 116.

be easily removed without disturbing any other part, so as to facilitate inspection and cleaning of the water spaces.

The pistons and piston rods are water-cooled. The pistons have coned faces, and are cast with pairs of internal diagonal bracing ribs, giving great stiffness and strength.

Ignition is on the low tension make-and-break system, and triplicate igniters at each cylinder end are provided.

The gas admission valve is mounted flexibly on the spindle of the main admission valve, so that both valves can close tightly, thus preventing back-firing, even should the valve seats become unequally worn.

The exhaust valve boxes and valve seats are of patented design, and consist of a separate outer casing, inner casing, and valve seat, all of which are water-cooled, so that water circulation in the exhaust valves themselves is unnecessary. The arrangement of the joint between the exhaust box and the cylinder is also of patented design, and such as to render any leak of gas at this joint, or any leak of water at the joint of the valve seat to the valve box, immediately visible. This is important, as if unchecked a gas leak at the cylinder joint may lead to cracking of the cylinder.

Governing is effected by throttling the supply of gas and air, the proportions being also varied at light loads. The governor is usually of the servo-motor type; the centrifugal element performs the light duty of controlling the admission of pressure oil to a servo-motor cylinder, when the oil acting on a piston of that cylinder provides ample force to move the throttle valves.

Table No. LXXXII. gives the standard sizes, power ratings, and other leading particulars of the Galloway Gas Engines. The normal powers, it should be observed, are based on a mean effective pressure of 60 lb. per square inch. Experience shows that this comparatively low rating is justified by increased freedom from wear, and by long life of the working parts. The "maximum continuous" loads are 10 per cent. in excess of the normal, and can be carried for hours without ill effects. "Momentary overloads" 20 per cent. above the normal rating may be carried for short periods. Twin tandem engines have, of course, double the power of the corresponding single tandem.

TABLE LXXXII.

GALLOWAY GAS ENGINES: FOR ELECTRIC GENERATORS.

Brake H.P.			Speed.	Weight without flywheel (approximate).	Approximate floor space (for dimensions G, H, I, K, see Fig. 117).			
Normal continuous.	Maximum continuous.	Maximum momentary.			G.	H.	I.	K.
			R.P.M.	tons.	ft. ins.	ft. ins.	ft. ins.	ft. ins.
510	560	610	150	70	10 8	40 7	10 6	9 6
660	725	790	136	85	11 8	42 1	11 6	11 2
770	850	925	125	110	12 4	45 0	12 2	11 6
925	1000	1100	107	140	13 2	49 6	13 6	12 2
1200	1300	1440	107	180	14 9	52 2	14 1	13 2
1450	1600	1750	107	215	14 9	58 9	14 9	13 6
1400	1540	1680	94	235				
1680	1850	2020	94	275	—	—	—	—
1820	2000	2180	94	290				
2150	2360	2580	94	330	14 9	62 2	16 5	14 5
2320	2550	2780	94	345				
2500	2750	3000	94	365	—	—	—	—
2700	2970	3240	88	400	—	—	—	—

The floor space occupied by the engines is obtainable from

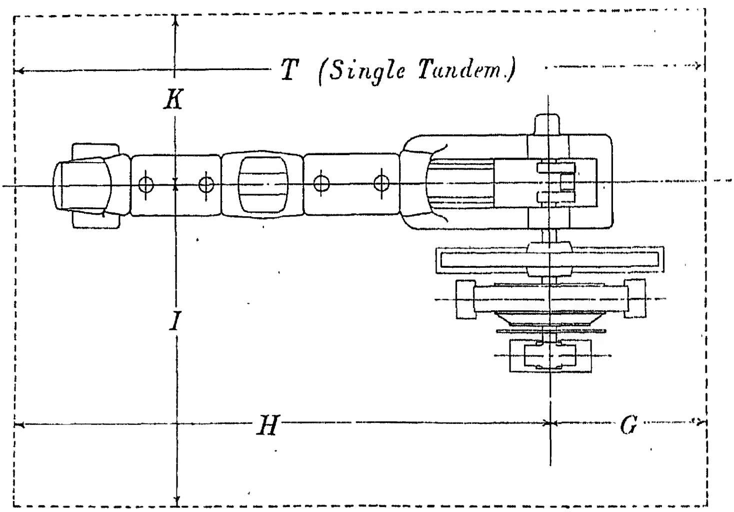


FIG. 117.—Floor Space of Galloway Gas Engines.

the dimensional diagram in Fig. 117 and from the figures given in the last table, the width required for twin tandem engines

being about 50 per cent. in excess of that for the single tandem type. The speeds quoted are suitable for alternators; they may be exceeded for D.C. generators and in certain cases for alternators also, thus giving higher power ratings. The weights given are for single tandem engines and include the crank shaft; holding-down bolts and plates; lubrication pumps, oil shields, etc.; barring gear; standard air, gas, and exhaust receivers; and piping within the engine house. Air compressors for starting the engine, and centrifugal pumps for supplying the cooling water are not included. For twin tandem engines, the weights are about 85 per cent. greater.

The size of the fly-wheel varies considerably according to the design of the electrical generator employed. The fly-wheel effect of the rotating parts of certain types of generators exceeds very greatly that of other makes, and the total fly-wheel effect necessary for steady running also depends upon the electrical design. For approximate purposes, however, the weights of the fly-wheels for engines of the sizes set out in Table No. LXXXII. may be taken as ranging from about 20 tons for the smallest engine to about 140 tons in the case of the largest.

Table No. LXXXIII., p. 290, gives the sizes, dimensions, weights and approximate pre-war cost of suction gas engines of the "electric lighting" type as manufactured by Messrs. Crossley Brothers, Ltd., of Manchester.

In the case of the larger sizes, the heat consumption of the engine per B.H.P. hour is as follows: at full load, 9500 B.Th.U.; at $\frac{3}{4}$ load, 10,450 B.Th.U.; and at $\frac{1}{2}$ load 11,600 B.Th.U. These figures apply to situations at or near the sea level with a temperature not exceeding 62° Fahr.

Under normal conditions of operation and with the engine and gas producer plant generally in good condition, the fuel consumptions for the range of engines set out in Table LXXXIII. are as given in Table No. LXXXIV.

TABLE LXXXIII.

Crossley Suction Gas Engines: Electric Lighting Type

Brake H.P. Normal.	Brake H.P. Maximum.	Speed.	Overall dimensions. Length.	Overall dimensions. Breadth.	Overall dimensions. Height above foundation to top of fly-wheel.	Minimum height from floor level to crane hook.	Weights. Of fly-wheel.	Weights. Engine and fly-wheel (nett).	Depth of foundation on approved sub-soil.	Approximate pre war cost, engine and fly-wheel, f.o.r. at works.
		R.P.M.	ft. ins.	ft. ins.	ft. ins.	ft. ins.	cwt.	cwt.	ft. ins.	£
66	73	210	14 3	9 1	5 6	10 6	112	225	5 0	344
85	95	190	16 0	10 9	6 2	12 6	166	333	5 3	500
117	130	180	17 6	10 9	6 7	13 0	240	525	6 0	690
80	88	230	11 10	10 6	5 1	10 0	60	192	4 0	410
96	106	220	13 9	11 4	5 3½	10 6	84	250	5 0	500
132	146	210	14 3	12 0	5 6	10 6	123	316	5 0	650
170	190	190	16 0	13 10	6 2	12 6	176	457	5 3	910
234	260	180	17 6	16 0	6 7	13 0	275	688	6 0	1220

Note.—The first three sizes are single cylinder engines, and the other five are double cylinder engines.

TABLE LXXXIV.

Crossley Engines and Gas Plants: Fuel Consumptions.

(Maximum power of engines: 73 to 260 B.H.P.)

Producer fuel and calorific value per lb.	Fuel consumptions per B.H.P. hour. Full load.	¾ load.	½ load.	¼ load.
	lbs.	lbs.	lbs.	lbs.
Anthracite (14,800 B.Th.U.) .	0·82 to 0·8	0·92 to 0·9	1·11 to 1·1	1·63 to 1·59
Bituminous coal (13,000 B.Th.U.)	1·25	1·4	1·72	2·48
Coke or charcoal (12,400 B.Th.U.)	0·98 to 0·95	1·1 to 1·07	1·35 to 1·3	1·95 to 1·9
Waste wood (theoretically dry, 7000 B.Th.U.) . . .	2·0	2·22	2·76	3·9

The figures apply to situations at or near sea level with a temperature not exceeding 62° F.

For the above consumptions to be guaranteed, the maximum power of the gas plant must be equal to that of the engine.

The following results were obtained with a small suction gas plant and engine of 26 B.H.P. during a run of 12 hours, the atmospheric conditions being: temperature 48° Fahr.; barometer 29·5 inches. The fuel employed in the gas producer was picked screened anthracite having a calorific value of 16,000 B.Th.U. per lb., and the average consumption at full load was 0·742 lb., equivalent to 11,872 B.Th.U. per B.H.P. hour. The water used in the producer (vaporizer) amounted to 2·14 gallons per hour, and in the scrubber to 26·3 gallons per hour, while the evaporation from four jacket cooling tanks was 0·71 gallon per hour.

Fig. 118 shows an installation of six twin cylinder Crossley engines each of 190 B.H.P. at the works of Messrs. British and Colonial Aeroplane Co., Bristol. The fuel supply for this installation is obtained from waste wood suction gas plant.

The following Table No. LXXXV. gives the sizes, dimensions, weights, and approximate pre-war costs of multi-cylinder horizontal engines as manufactured by The Premier Gas Engine Company, Ltd., of Sandiacre, near Nottingham.

TABLE LXXXV.

PREMIER GAS ENGINES: MULTI-CYLINDER HORIZONTAL TYPE.

Brake H.P.		Speed.	Overall dimensions. (Engine and dynamo.)						Height from floor level to crane hook.		Weights. (Electric type.)			Depth of foundations on approved sub-soil.		Approximate cost (pre-war) of engine f.o.r. at works.
Normal.	Maximum.		Width.		Length.		Height.				Fly-wheel.		Engine and fly-wheel.			
		R.P.M.	ft.	ins.	ft.	ins.	ft.	ins.	ft.	ins.	tons	cwt.	tons.	ft.	ins.	£
126	150	220	13	0	13	0	7	0	10	0	4	19	16½	4	6	590
150	190	210	13	6	14	0	7	0	10	0	6	12	19¾	5	0	700
189	225	220	16	0	13	0	7	0	10	0	4	19	20½	5	0	850
252	300	220	20	0	13	0	7	0	10	0	4	19	25	5	0	1150
300	380	210	21	0	14	0	7	0	10	0	6	12	30	5	0	1350
368	468	200	23	0	14	9	7	3	11	0	8	5	38	6	0	1700
500	600	190	25	0	16	0	7	6	11	6	10	0	46	7	0	2300
750	900	190	28	0	15	8	7	6	11	6	10	0	66	7	0	3500
1000	1200	190	35	6	15	8	7	6	11	6	10	0	82	7	0	4500

Larger sizes than those indicated in the table have been built, Premier engines of 2000 B.H.P. having been in operation for some considerable time.

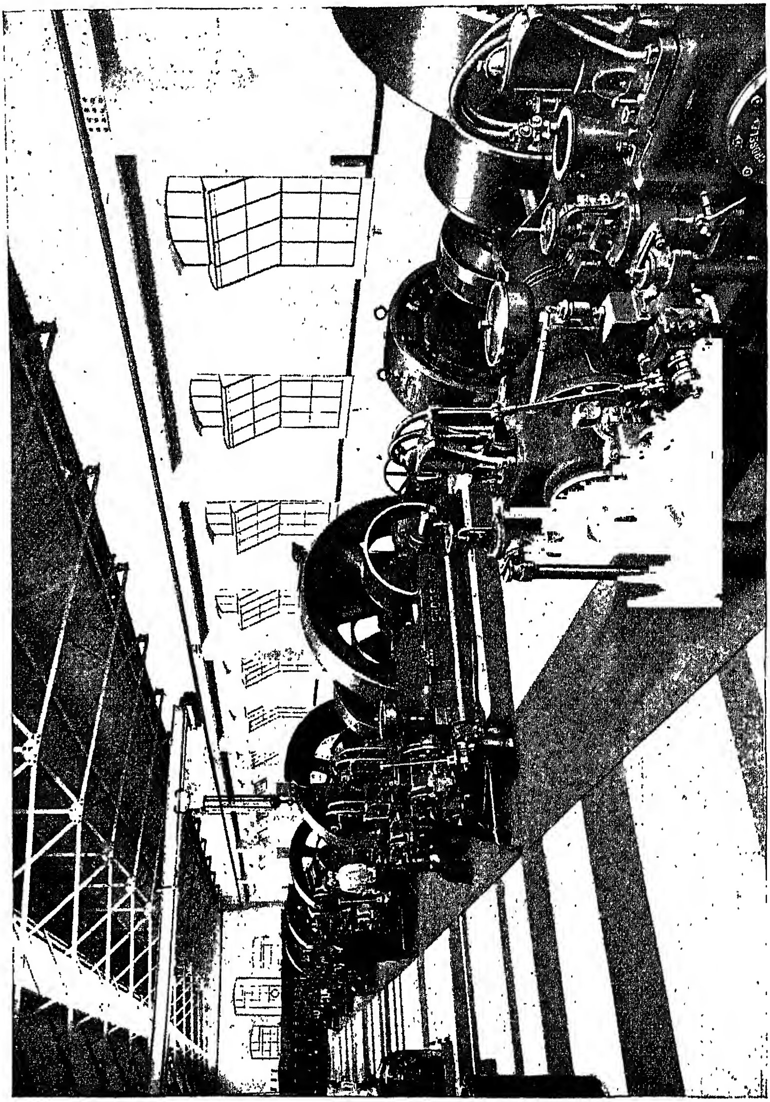


Fig. 118.

The larger sizes from about 250 B.H.P. are of the positive scavenger type. They are constructed with a differential piston and an auxiliary cylinder into which a charge of air is drawn during the suction stroke. The pressure of this air only rises to about 5 lb. above that of the atmosphere during the compression stroke, and falls to atmospheric pressure again during the working stroke. During the fourth stroke, the piston expels the products of combustion from the working cylinder in the usual way, and the auxiliary charge of air, which is again compressed, is admitted to the working cylinder so as to scavenge it and leave it filled with pure and comparatively cool air. The exhaust valve remains open until after the crank has passed the dead centre so that the pressure in the working cylinder may fall to that of the atmosphere. The scavenging air also serves to cool the valves and internal surfaces which come into direct contact with the flame.

The advantages claimed for this type as compared with non-scavenger engines are: (*a*) the possibility of working with higher compressions without danger of premature ignition; and (*b*) the smaller loss of heat to the cylinder walls in proportion to the power developed and the consequent gain in thermal efficiency.

The following results were obtained during a series of tests under ordinary working conditions at an installation comprising three four-cylinder horizontal Premier engines of 300 B.H.P. each direct coupled to 200 K.W. generators, the fuel supply being derived from bituminous suction producers. The calorific value of the gas ranged from 113 to 116 B.Th.U. per cubic foot during the tests, and at loads of 199·5, 160·3, and 110·7 K.W. respectively, the fuel consumptions were 10,900, 12,080, and 14,900 B.Th.U. per K.W.H. During a period of six months running at a load factor of 65 per cent., the fuel consumption amounted to 1·82 lbs. per unit distributed to the works.

Fig. 119 shows an installation of two horizontal four-cylinder Premier engines of 500 B.H.P. at the works of the Hoffmann Manufacturing Co., Chelmsford. The engines are coupled to D.C. generators of 360 K.W., and the fuel supply is obtained from the ammonia recovery producer plant illustrated in Fig. 113. An analysis of the results of six months' operation of one 30-ton

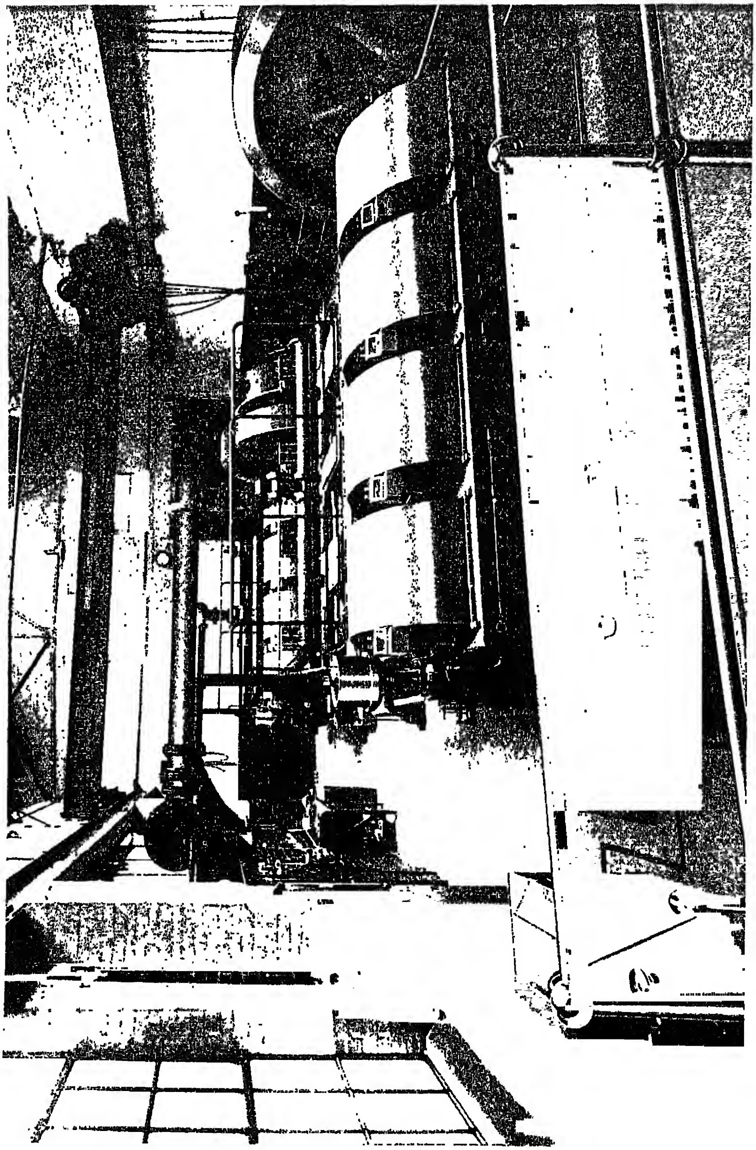


FIG. 119.

producer unit supplying gas to two engines and also for other purposes is given in Mr. Patchell's paper, previously referred to, from which the following figures are taken.

The total coal gasified during the period was 3255 tons (average calorific value 11,333 B.Th.U. per lb.), corresponding to an average load upon the producers of about 75 per cent. during working hours, but only 42·7 per cent. of the total make of gas was used in the engines, the remainder being employed for heating purposes. The engines generated over 1·83 million units during the period, corresponding to an engine load factor of 73·6 per cent. during running hours. Apportioning the amount of coal gasified and making allowances for the steam raised in exhaust boilers and by burning the tar from the gas plant in Lancashire boilers, the nett coal consumption of the power plant per K.W.H. was 1·51 lb., representing an overall thermal efficiency of 19·9 per cent. At load factors of 102 per cent. and 84 per cent. respectively, the gas engine generators required 13,062 and 13,759 B.Th.U. per K.W.H., the engines alone at the same load factors requiring 8968 and 9368 B.Th.U. per B.H.P. hour. The coal employed contained about 1·3 per cent. of nitrogen, of which about 65 per cent. was recovered, the yield of sulphate of ammonia averaging about 90 lb. per ton of coal gasified.

Vertical Gas Engines.—Vertical gas engines in large units up to and exceeding 1500 B.H.P. have been in successful operation for many years and their design has reached a high standard of excellence. In cases where economy in ground space is an important consideration, vertical engines show a substantial advantage as compared with the majority of horizontal engines of equal capacity. For example, a set of three 1500 H.P. vertical engines could be accommodated with a ground space of 0·85 square foot per B.H.P., whereas a corresponding set of horizontal tandem engines would require about 1·9 square feet per B.H.P.

The following Table No. LXXXVI. gives the sizes, dimensions, and weights of vertical tandem engines as manufactured by the National Gas Engine Company of Ashton-under-Lyne, England :—

TABLE LXXXVI.

NATIONAL VERTICAL GAS ENGINES.

Brake H.P.		Speed.	Overall dimensions.			Minimum height from floor level to crane hook.	Weights.		
Normal.	Overload.		Length.	Width.	Height.		Of fly-wheel.	Heaviest lift.	Total.
		R.P.M.	ft. ins.	ft. ins.	ft. ins.	ft. ins.	tons.	tons.	tons.
300	330	300	11 7¼	11 3	14 3	23 3	5	5¼	31½
450	495	300	14 7¼	11 3	14 3	23 3	5	8	43
600	660	300	17 7¼	11 3	14 3	23 3	5	9¾	53
750	825	200	18 0	12 10	18 2	29 6	13½	14	78
1000	1100	200	21 9	12 10	18 2	29 6	13½	19	98
1500	1650	200	31 7¾	15 9	18 5	29 6	13½	15½	149

With regard to foundations, a depth of from 6 to 8 feet of concrete is required for good ground, but in some cases rafts and piling may prove necessary. The concrete foundations should consist of a mixture of 1 part of cement, 3 parts of sharp sand, and 6 parts of broken stones, and for grouting up under the engine a mixture of 1 part of cement and 1 or 1½ parts of sharp sand should be used.

Fig. 120 shows a cross-section of a standard National Vertical gas engine. These engines, in sizes ranging from 300 to 2000 B.H.P., operate on the "Otto" or 4-cycle system and have from 2 to 6 cranks. Two cylinders in tandem (7, 12) are placed over each crank, and are fired alternately, thus giving a working stroke on every downward stroke, and a compression stroke in either the top or bottom cylinder on the upward movement. The space between the top piston (13) and the intermediate cover (9) constitutes a buffer cylinder in which air is compressed on each downstroke. On account of the cushioning of the moving parts in both directions and of the number of cranks, the turning effort is very even and a cyclic irregularity as small as $\frac{1}{200}$ or $\frac{1}{300}$ can easily be obtained. The inlet and exhaust valves (16, 19) of the top cylinder are "staggered" relatively to those of the bottom cylinder to facilitate removal of the valves for examination. The valves are operated by push rods (25) from a camshaft (27), and the motion work is completely enclosed and all

bearings, pins, etc., provided with forced lubrication through an oil inlet pipe (33, 34). Governing is effected by means of a

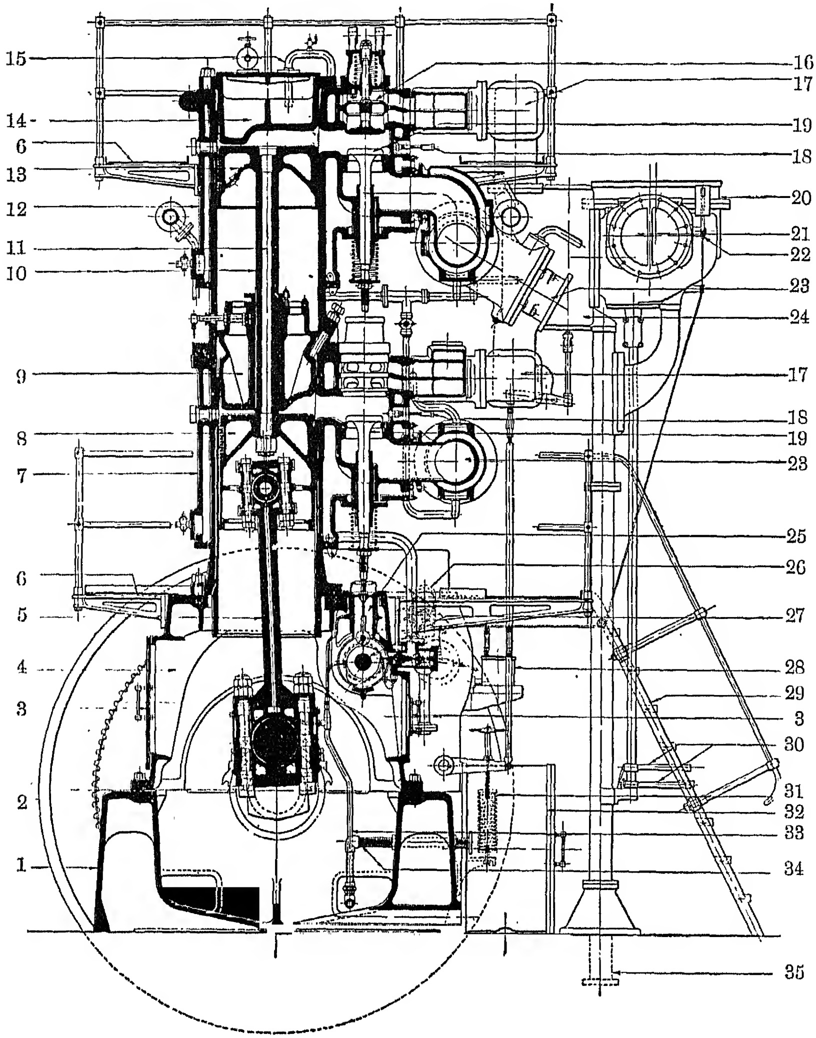


FIG. 120.

throttle valve controlled by a centrifugal governor, and the engines are so designed that a change over from one kind of

gaseous fuel to another kind can be effected without the alteration being noticeable on the drive. The cylinders are provided with water jackets, and the covers (9, 14) are also water-cooled, but no moving parts are water-cooled. Ignition is effected by high-tension sparking-plugs (18), two plugs being provided in each cylinder. The bedplate (1) of the smaller engines is cast in one piece and serves as an oil reservoir in which the oil strainers and pumps are placed. The crank-case (4) is cast in one or two pieces according to the size of the engine, and is provided with large inspection doors (3) at the front and back. The gear for barring the engine round to the starting position is operated either by hand or, in the case of the largest engines, by a chain drive from an electric motor. The engine is started by admitting compressed air, at a pressure of from 250 to 350 lb. per square inch, to one of the bottom cylinders. The air compressors can be of the single stage or two-stage type and driven by an electric motor or by a separate gas or oil engine according to circumstances.

Fuel Consumption.—For estimating purposes, the heat consumption of large gas engines at various loads may be taken at the following figures per B.H.P. hour, namely: 9500 to 10,000 B.Th.U. at normal full load, 11,250 B.Th.U. at $\frac{3}{4}$ load, 13,500 B.Th.U. at $\frac{1}{2}$ load, and 21,000 B.Th.U. at $\frac{1}{4}$ load.

The fuel consumption of a suction producer and gas engine installation working a normal full load may be taken at 0·9 lb. of anthracite or 1·25 lb. of coke per B.H.P. hour. With bituminous coal and recovery producer plant, the fuel consumption will be about 1·3 lb. per B.H.P. hour. As previously stated, the stand-by losses are small, representing from 1 to 3 per cent. of the full load consumption.

Heat in Exhaust Gases.—From 25 to 35 per cent. of the thermal units supplied to operate a gas engine are rejected in the exhaust gases as waste heat, and considerable economies can be effected by utilizing this waste heat for drying or heating purposes, for example, for steam raising by means of exhaust heated boilers. In the case of large gas engines and with an efficient boiler arrangement, the steam raised per B.H.P. hour will amount to from 2 to 2·2 lb. at a pressure of from 80 to

100 lbs. per square inch. The boilers are usually erected close to the exhaust outlet from the main cylinder, and can be fitted with a special grate so that hand firing may be resorted to if steam is required when the main gas engine plant is not running. During such periods, either coal or the tar obtained as a by-product from the gas producer plant may be used as fuel.

Water Consumption.—The amount of water required for cooling the cylinders of gas engines may be taken at the following figures per B.H.P. hour, namely: about 6·5 gallons if at 50° Fahr., about 7·75 gallons if at 60° Fahr., about 9·75 gallons if at 70° Fahr., and about 12 gallons if at 80° Fahr. This water is, of course, not all wasted, as it may be re-cooled in cooling towers. The heat to be got rid of in this way amounts to about 3500 B.Th.U. per B.H.P. hour, and an evaporation of 3 per cent. may be taken as a maximum in most countries. The water employed should be clean and free from acids or alkali so as to avoid scaling or corrosion of the cylinder jackets, etc., and should be tested to ascertain the amount of scale formed up to temperatures of 150° Fahr. If possible, the inlet temperature should not exceed 75° to 80° Fahr., and the outlet temperature 110° to 130° Fahr. The amount of cooling water required does not vary materially between full load and half load.

Suction producers require up to 1 gallon of water for scrubbing and steam raising per B.H.P. hour, and recovery producers a much larger quantity, namely, about 4 gallons per B.H.P. hour, as well as about 30,000 gallons for the sulphate plant per ton of sulphate recovered as a finished product.

The water consumption of a gas engine power house is thus by no means negligible. The Author may refer, in this connection, to a case in which he was advising upon a power installation for some important mines where water was of great value in the hot season. The loss of water from a gas engine installation was shown to be considerably greater than the evaporation from cooling towers for the condensers of an equivalent steam plant, and this became so serious a factor in the comparison that steam plant was adopted. In this instance, the guarantees were 12·2 gallons per K.W.H. for all purposes.

Oil Consumption.—The consumption of lubricating oil by

large gas-driven generators ranges from 0·2 to 0·37 gallon per B.H.P. hour at normal full load, and is not materially reduced at decreased loads. Including the requirements of auxiliaries, a figure of 0·45 gallon per B.H.P. hour at full load may be taken for estimating purposes. The forced lubrication system of large engines working for long hours or in a heated atmosphere should be fitted with an oil cooler. The pressure of the water in the cooling pipes should be less than that of the oil in the cooler, so that in the event of leakage there is no tendency for the water to enter the oil circulating system and injure the bearings.

Repairs and Maintenance.—With regard to the cost of repairs and maintenance at gas engine power houses, the principal risks to be faced are the possible fracture of pistons and cylinder liners or bodies, due to the large variations in temperature during each cycle, and also of crank shafts. The wear in other moving parts is not appreciably greater than in steam engines, and the regrinding of valves is found, in practice, not to constitute a serious item. The cost of repairs to producers and auxiliary apparatus is also found to be small. Under pre-war conditions of cost, the annual charge for the repair and maintenance of gas engines varied from 1 to 2 per cent. of the initial capital outlay, the higher figure applying in the case of engines of older and inferior designs. For a well-kept power station, the annual charge in respect of the gas engines should not exceed 1·5 per cent. upon their capital cost. For the whole of the power house plant, including gas producers, the annual cost of repairs and maintenance may, for estimating purposes, be taken at from 1 to 1·5 per cent. of the corresponding capital outlay.

Depreciation.—The allowance to be made for depreciation depends upon how the engines are worked and upon the load factor of the plant. If the engines are well looked after, the annual charge for depreciation should not exceed from 4 to 5 per cent. of their capital cost. Taken over the whole plant, a charge of from 3 to 4 per cent. on the capital outlay may generally be allowed.

Labour.—The labour requirements of a large gas-engine installation are considerably greater than those of a steam

turbine power house of equivalent size, but in small stations there is not much difference. One greaser is allowed to each engine of large size, together with a fair proportion of skilled supervision.

Capital Costs.—Under pre-war conditions, the average cost of large gas engines including fly-wheel varied from about £6 to £7·5 per B.H.P. according to the size.

Fig. 121, taken from the paper by Andrews and Porter

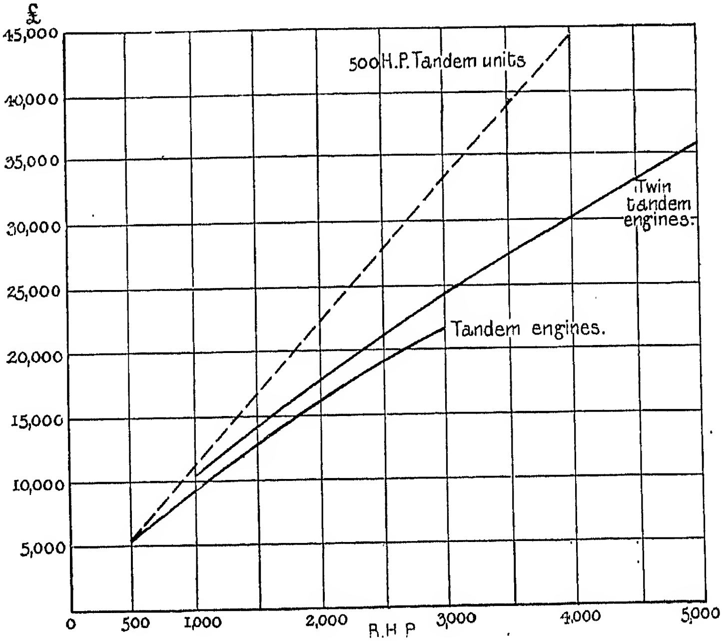


FIG. 121.

previously referred to, shows the approximate pre-war capital cost of horizontal gas engines having outputs varying from 500 to 5000 B.H.P. (single and twin tandem) direct coupled to generators and erected complete with pipe-work, foundations, and fly-wheels designed for a cyclic irregularity of $\frac{1}{250}$. The figure also gives the capital cost of equivalent installations comprising a number of units each of 500 B.H.P.

Gas Engine Power Houses.—From the point of view of power house design, the question of installing gas engines and

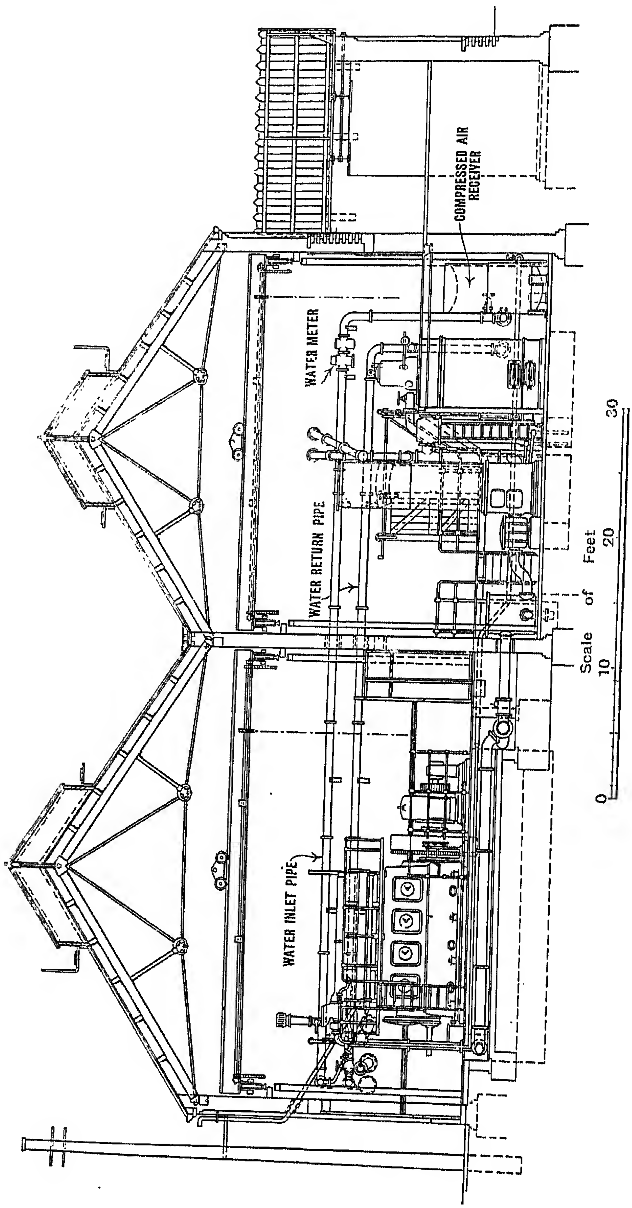

COMPRESSED AIR RECEIVER
WATER METER
WATER RETURN PIPE
WATER INLET PIPE
Scale of Feet
0
10
20
30

FIG. 122.

gas producer plant has, as a general rule, only to be considered in the case of small stations. Although gas engine power houses having an installed capacity of 10,000 B.H.P. and over have been constructed, they are relatively few in number compared with steam power houses of corresponding sizes; moreover, they usually owe their existence to special local circumstances, such as the availability of large supplies of waste power gas at iron works or coke ovens.

An example of a small gas power house, erected at Swindon for the carriage and wagon works of the Great Western Railway, is illustrated in Fig. 122, a general view of the plant being shown in Fig. 123. The installation consists of two vertical engines direct coupled to D.C. generators, each engine having a capacity of 250-290 B.H.P. and a speed of 225 R.P.M. The engines are supplied from suction gas producers each 6 feet 3 inches in height by 3 feet 9 inches in diameter and provided with two scrubbers each 16 feet high by 3 feet 6 inches diameter. The fuel (anthracite) is shovelled direct into the charging hoppers from an elevated platform. The consumptions of anthracite per B.H.P. hour are as follows: 0·9 lb. at full load, 0·97 lb. at three-quarter load, and 1·1 lb. at half load. The thermal efficiencies (B.H.P.) at full load are 19·3 per cent. for the engines and producers, and 25·5 per cent. for the engines only.

TABLE LXXXVII.

SMALL GAS POWER HOUSE: COMMERCIAL TESTS.

Items.	Load.		
	Full.	Three-quarter.	Half.
Length of run (hours)	223	125	136
Output:			
Average K.W.	312·3	228·3	159·6
K.W. hours	69,650	28,540	21,710
Coal:			
Average calorific value (B.Th.U. per lb.)	14,392	14,392	14,392
Total gasified (lbs.)	115,289	54,143	47,775
Gasified per hour (lbs.)	517	433	351
Gasified per K.W. hour (lbs.)	1·654	1·697	2·20
B.Th.U. per K.W. hour	23,700	27,280	31,650
Percentage efficiency	14·35	12·65	10·78

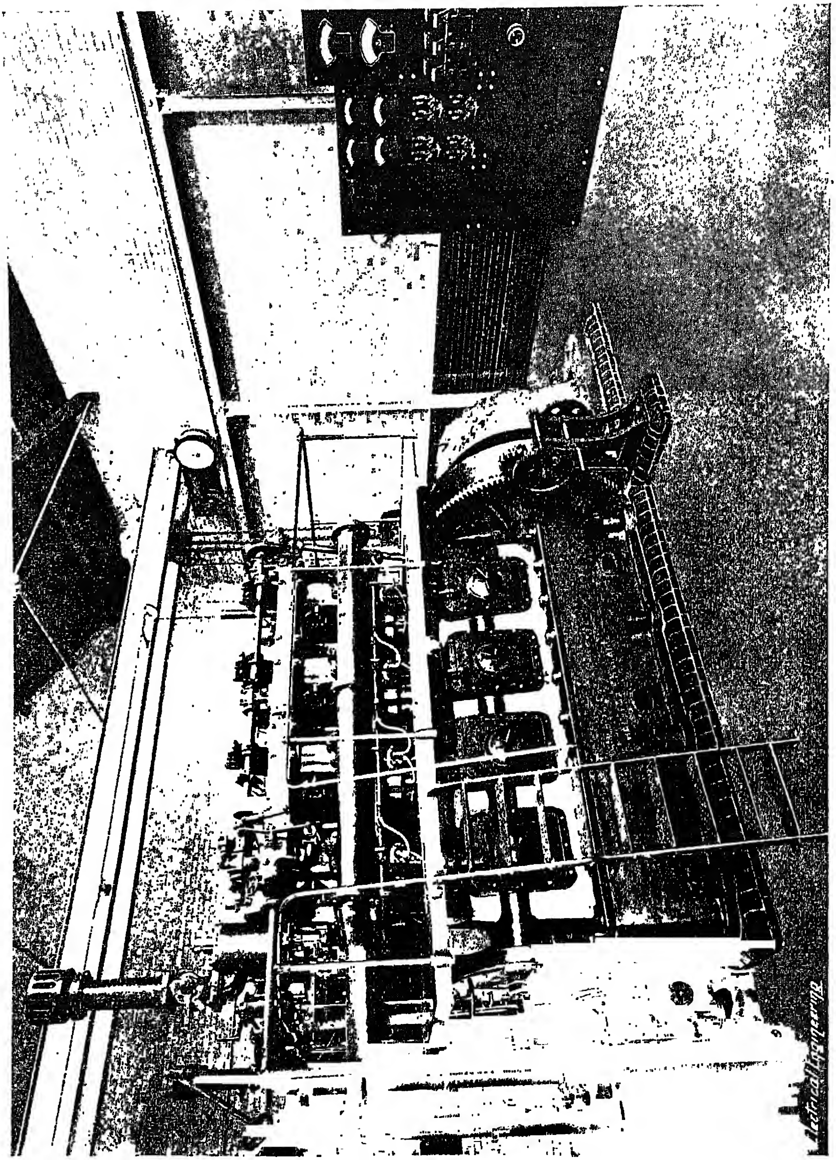


FIG. 123.

The commercial results of a thirty-day test of another small installation at the Richmond Works of the American Locomotive Company, Va., are recorded by J. R. Bibbens ("American Institution of Electrical Engineers," 1908, Vol. 27) as given in Table No. LXXXVII, p. 303. The plant consisted of one horizontal tandem gas engine of the double-acting type giving two impulses per revolution and operating on producer gas generated by a pair of 9 foot bituminous producers.

With regard to large gas power houses, a diagrammatic illustration of an installation designed to have a maximum output of 8000 K.W. is given in Figs. 124 and 125, taken from the paper by Messrs. Andrews and Porter previously referred to. The lay-out shown comprises seven single-tandem horizontal gas engine generators each of 1450 K.W., four ammonia recovery producers, four non-recovery producers, and accessory plant. The assumed annual load factor of the power house was 24 per cent., and the recovery producers were to be used for a portion of the plant working almost continuously at a high load factor, and the non-

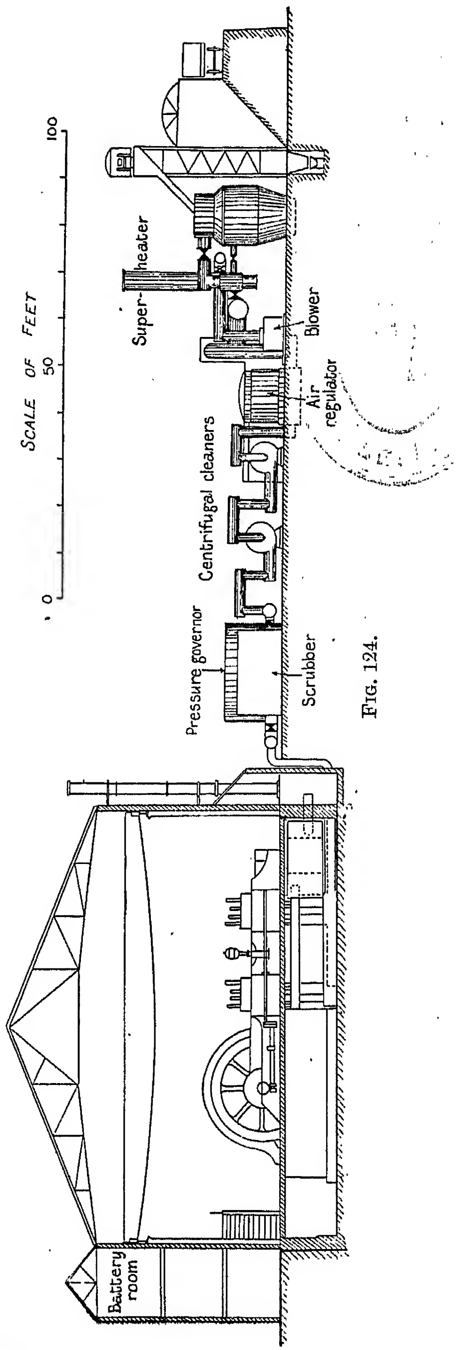


Fig. 124.

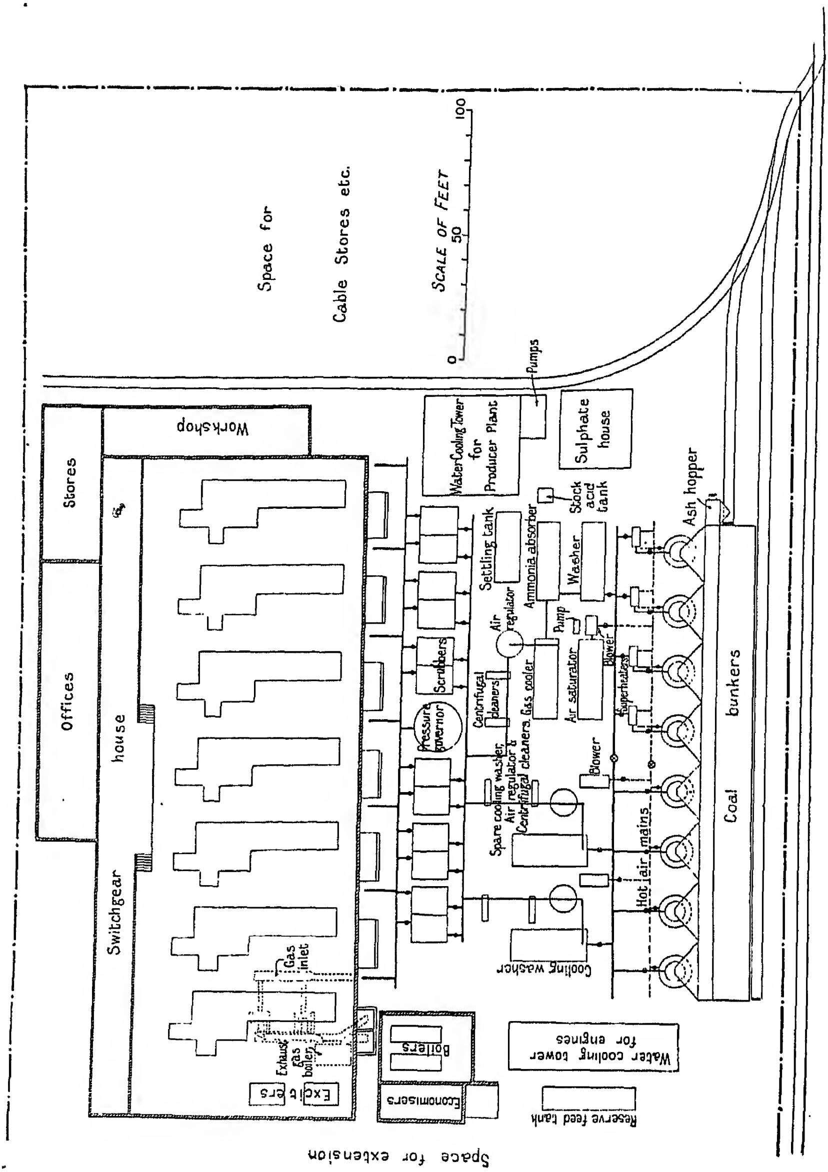

Space for
Cable Stores etc.
SCALE OF FEET
0
50
100
Pumps
Workshop
Stores
Offices
Switchgear house
Water Cooling Tower for Producer Plant
Sulphate house
Settling tank
Stock acid tank
Ash hopper
Ammonia absorber
Washer
Air regulator
Pump
Scrubbers
Blower
Superheaters
Pressure governor
Centrifugal cleaners
Gas cooler
Air saturator
Spare cooling washer, Air regulator & Centrifugal cleaners
Blower
Hot air mains
Coal bunkers
Cooling washer
Gas inlet
Exhaust gas boiler
Exciters
Boilers
Economisers
Water cooling tower for engines
Reserve feed tank
Space for extension

FIG. 125.

recovery producers for dealing with the peak load and remaining portion of the total output. As will be seen on comparing the left- and right-hand sides of the lower portion of Fig. 125 the producer auxiliaries and lay-out are much simpler in the case of the non-recovery plant. For an annual load factor of 24 per cent., which may be taken as typical for small power houses for general supply, the coal consumption on an output of 21,000,000 units was computed by Andrews and Porter to be as given in Table No. LXXXVIII.:—

TABLE LXXXVIII.

COMPUTED COAL CONSUMPTION OF GAS POWER HOUSE.

(Maximum demand 8000 K.W.)

Items.	Coal consumption.	
	Total.	Per unit generated.
	tons.	lbs.
Useful output consumption at 1 lb. per unit	9,360	1·00
Engine-hours per annum: 17,450 at 800 lbs. per hour	6,230	0·66
Banked producer-hours per annum: 35 000 at 50 lbs. per hour	782	0·08
	16,372	1·74
Discrepancy factor (25 per cent.) covering variations in fuel quality, heating up cold boilers, leakages, and other contingencies	4,093	0·44
	20,465	2·18

The above figures correspond to an overall thermodynamic efficiency of 12 per cent. and approximate to the published commercial results obtained at several installations. It was estimated that of the total coal consumption, approximately 71 per cent., or 14,580 tons, would be gasified in the recovery producers.

To sum up, the capital cost of a combined producer and gas engine plant is somewhat higher than that of an equivalent amount of boilers, steam engines and auxiliaries. In the case

of small power houses, experience has shown that the cost of repairs at steam and gas-driven stations is not materially different while the cost of labour is practically the same. The reliability of gas engine plant, however, is not so pronounced as that of good steam plant, and its capacity for sustained overload is smaller, and these factors must be considered when designing any power house. Generally, it may be said that when the cost of fuel is low and the annual load factor to be anticipated is also low, gas engines will not compare economically with steam plant. Where fuel is costly and a high annual load factor can be relied upon, then there is a strong case for gas-driven plant. A combination of both steam and gas plant represents a compromise that should not be overlooked as regards capital expenditure and running conditions. The gas-driven sets could be utilized on the parts of each day curve giving the highest load factor, while the steam sets could be used on those parts of the curve having a shorter period and more uneven load. In addition, the steam plant would serve as a reserve and thus compensate for the present somewhat less reliability of the gas plant. This aspect of power generation is dealt with in a subsequent chapter together with the relative capital and running costs of steam and gas-driven power houses.

Oil Engines.—For small power houses and for light load plants in larger installations, a very great economy can be obtained by the adoption of oil engines, the best known of which is the Diesel engine.

The Author has had to make several investigations into the economics of small electricity supply undertakings with steam-driven sets and a poor annual load factor of less than 16 per cent. In such cases he has found that the addition of a Diesel set to care for the light loads effected a relatively great economy, considerably reducing the losses due to banking boilers, heating up steam ranges and running steam sets at light loads with their resultant increase in the consumption of steam and fuel per unit delivered to the switchboard. As an auxiliary in power houses thus situated, and also for isolated plants where an alternative supply of power cannot be purchased at a reasonable cost, the Diesel engine is to be highly recommended.

The working cycle of a Diesel engine differs from that of an ordinary gas engine in that air alone is drawn into the cylinder and compressed, the heat of compression causing the automatic ignition of the oil fuel which is sprayed into the cylinder during a measurable portion of the working stroke. In the case of a 4-cycle engine, air at atmospheric pressure is drawn into the cylinder during the first down-stroke, and is compressed on the return stroke to a pressure of about 450 to 500 lb. per square inch. This pressure corresponds to a temperature of 900° to 1000° Fahr. which is far above the flash-point of the oil fuel. During the first part of the third (or working) stroke, the oil is sprayed into the cylinder by means of compressed air, combustion proceeding at practically constant pressure for a period determined by the amount of oil fuel sprayed in; for the remainder of the stroke the products of combustion do work by expansion, and are expelled to the atmosphere during the fourth or exhaust stroke. It will be seen that there is no possibility of premature ignition; moreover, the absence of any explosion or sudden rise of pressure in the cylinder minimizes the strain on the working parts, and conduces to smooth running.

Diesel engines are quite adaptable for driving alternators in parallel, as a speed variation of not more than $\frac{1}{250}$ or $\frac{1}{300}$ can be secured with only a moderately heavy fly-wheel.

Figs. 126 and 127 show, diagrammatically, a 3-cylinder single-acting 4-cycle Diesel engine, and the general arrangement of a complete power house containing five Diesel-generator sets each having a capacity of 400 K.W. Each engine cylinder has three valves, viz. exhaust, air inlet and fuel inlet valves respectively, and one cylinder has an additional starting valve. The valves are all controlled by springs and are actuated by cams upon a half-speed shaft B. The oil fuel is stored in a tank N and is raised by means of a service pump O to overhead service tanks from which it is fed to a fuel pump C by gravity. The fuel is injected into the cylinder against the high pressure within the latter by means of compressed air from a storage receptacle G, which is charged by means of a 3-stage compressor F, the air being cooled after each stage (75, 400, and 750 lb. per square inch

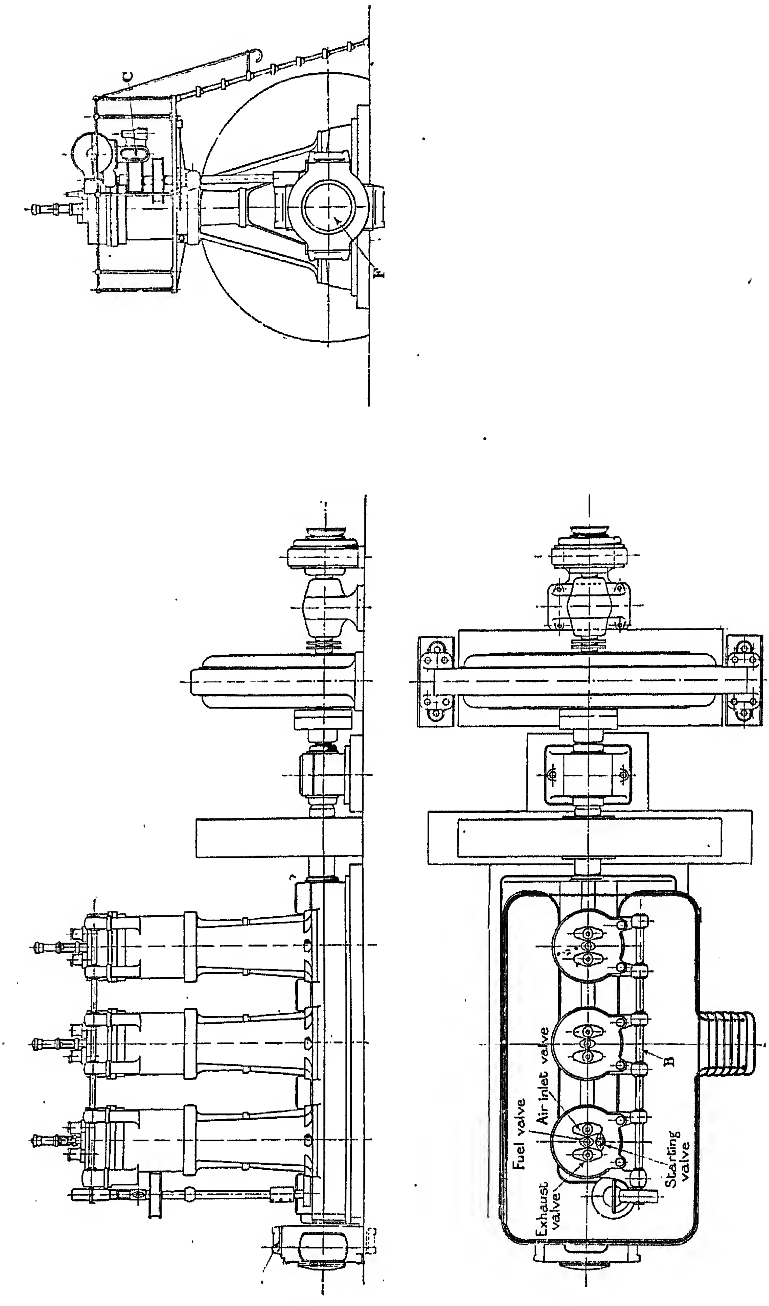
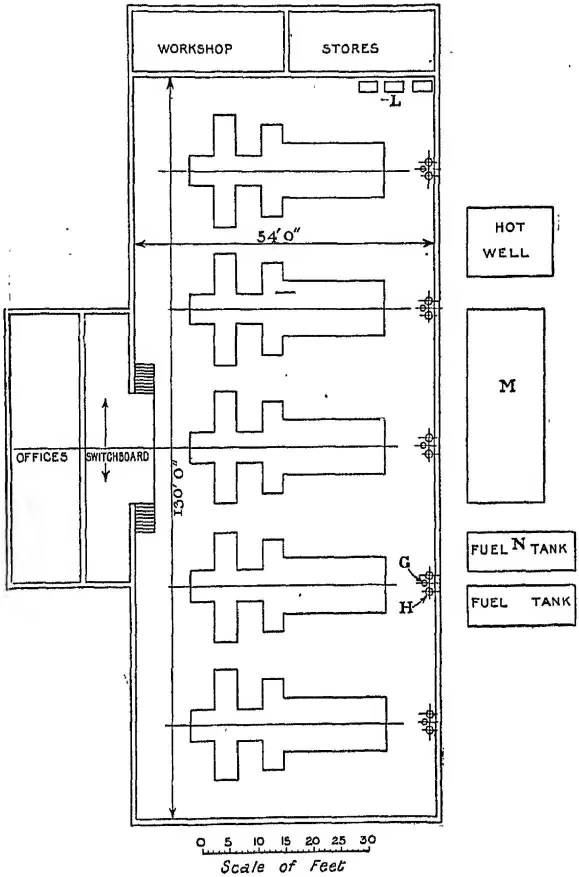
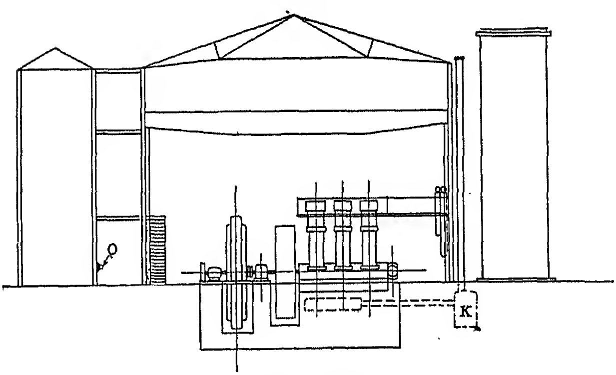

C
F
B
Fuel valve
Air inlet valve
Starting valve
Exhaust valve

FIG. 126.



Plan.



Cross-section.

FIG. 127.

respectively) by passage through water-cooled chambers. These chambers and the jackets of the engine cylinders and air pump are supplied with water by means of a circulating pump L. The engines exhaust into a silencing chamber K, and are started by means of compressed air stored in a starting reservoir H

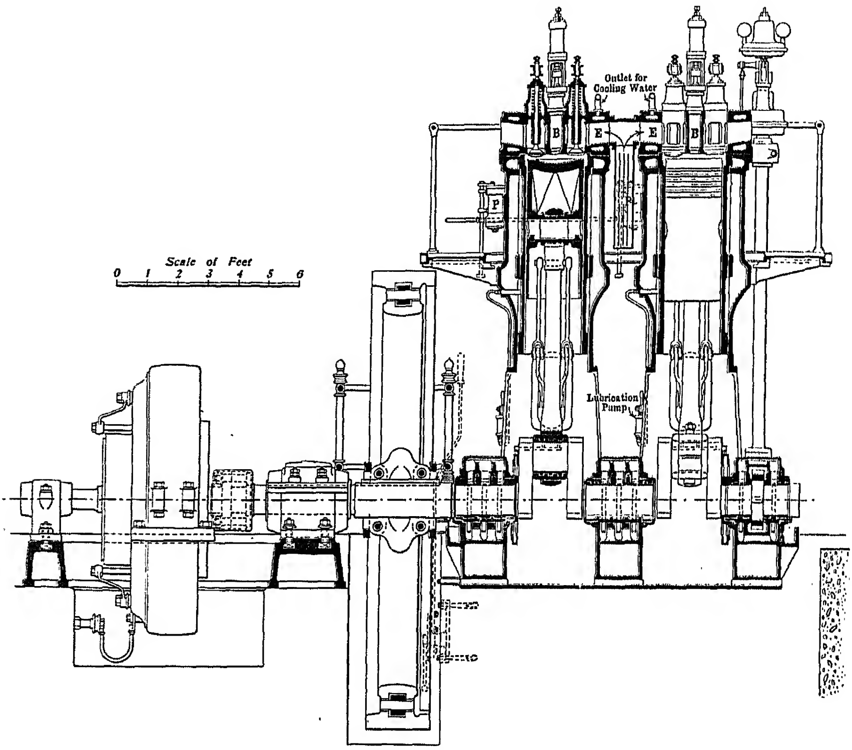


Fig. 128.

during a previous run. The pressure is maintained at about 800 lb. per square inch, and the reservoir is connected by means of an overflow valve with the air-blast reservoir G.

Fig. 128 shows a section through a 2-cylinder 250-H.P. Diesel engine, made by the Augsberg Engine Works. This engine runs at 155 R.P.M., and will develop 300 H.P. on overload. The stroke is 29 inches, and the cylinder diameter 19¾ inches. There are two fly-wheels, one 12 feet 2 inches in dia-

meter, weighing 7 tons, and the other 13 feet 9 inches in diameter, weighing 15 tons. The variation of angular velocity does not exceed $\frac{1}{140}$.

Fig. 128 A shows a cross section of the same engine. There are four valves on the cylinder; (1) the starting valve V, to admit the compressed air; (2) the suction valve E (Fig. 128) to

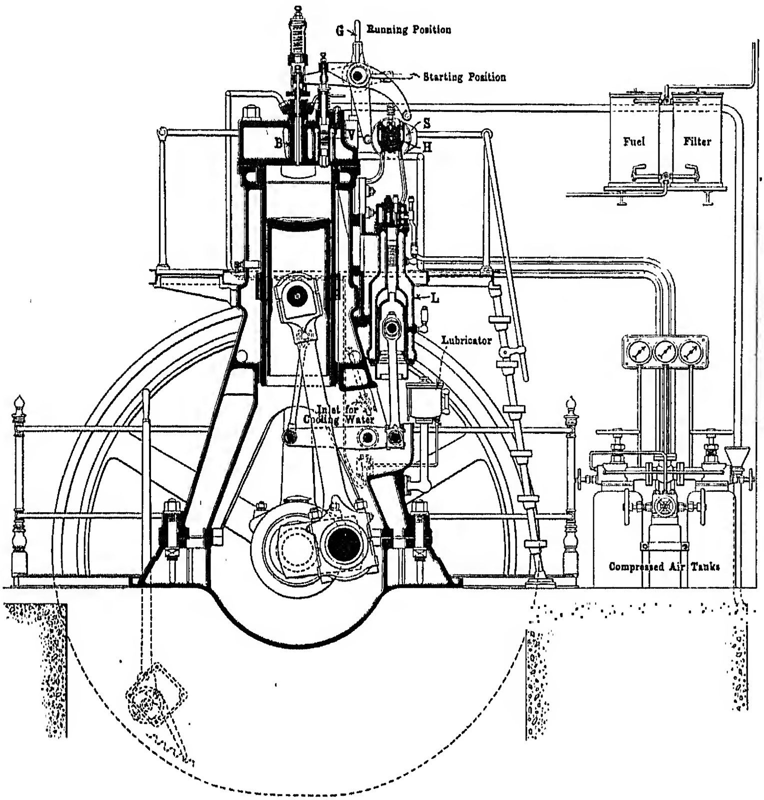


FIG. 128 A.

admit the air at atmospheric pressure; (3) the fuel valve B, to admit the liquid fuel; and (4) the exhaust valve. The valves are closed by springs, and opened by levers actuated by the cams S worked from the rocking shaft H. The shaft H is driven from the crank shaft by two worm wheels and a vertical shaft.

The fuel used is paraffin oil, obtained as a waste product from

the manufacture of paraffin by the distillation of tar from bituminous coal. The flash point is 212° C., and the calorific value about 17,000 B.Th.U. per pound. Very little residue is found in the cylinders.

Table No. LXXXIX. gives the sizes, dimensions, pre-war prices, and other leading particulars of "Mirrlees" Diesel engines as manufactured by Messrs. Mirrlees, Bickerton & Day, of Stockport, England.

TABLE LXXXIX.

"MIRRLEES" DIESEL ENGINES: SIZES AND OTHER PARTICULARS.

Size.	Number of Cylinders.	Speed.	Dimensions. Length.		Dimensions. Width.		Dimensions. Height to crane hook.		Weights. Fly-wheel.	Weights. Engine and fly-wheel.	Approximate depth of foundations on approved sub-soil.		Approximate cost. (Pre-war.)
B.H.P.		R.P.M.	ft.	ins.	ft.	ins.	ft.	ins.	tons.	tons.	ft.	ins.	£
50	1	250	8	9	8	6	13	6	$4\frac{3}{4}$	$13\frac{3}{4}$	6	0	685
100	2	250	11	6	8	6	13	6	$4\frac{3}{4}$	$16\frac{3}{4}$	6	0	1040
150	3	250	14	1	8	6	13	6	$4\frac{3}{4}$	$23\frac{3}{4}$	6	0	1395
200	4	250	16	7	8	6	13	6	$4\frac{3}{4}$	28	6	0	1750
300	6	250	21	9	8	6	13	6	$4\frac{3}{4}$	39	6	0	2495
240	3	250	18	0	9	0	14	0	10	40	6	6	2125
320	4	250	21	0	9	0	14	0	10	52	6	6	2670
375	3	200	22	6	11	0	21	0	15	67	7	6	3570
500	4	200	27	6	11	0	21	0	15	84	7	6	4570
750	6	200	34	0	11	0	21	0	15	110	7	6	6595

The first five sizes are of the open type, the next two of the enclosed type with forced lubrication, and the last three of the "crosshead" type, enclosed and fitted with forced lubrication.

An illustration of a standard 500 B.H.P. "crosshead" type "Mirrlees" Diesel engine is shown in Fig. 129.

Fuel Oils for Diesel Engines.—Almost any kind of clean fuel oil containing not more than 0·5 to 1 per cent. of sulphur and free from acids can be successfully employed with Diesel engines. The average calorific values and other particulars of various fuel oils are given in Table No. XC.

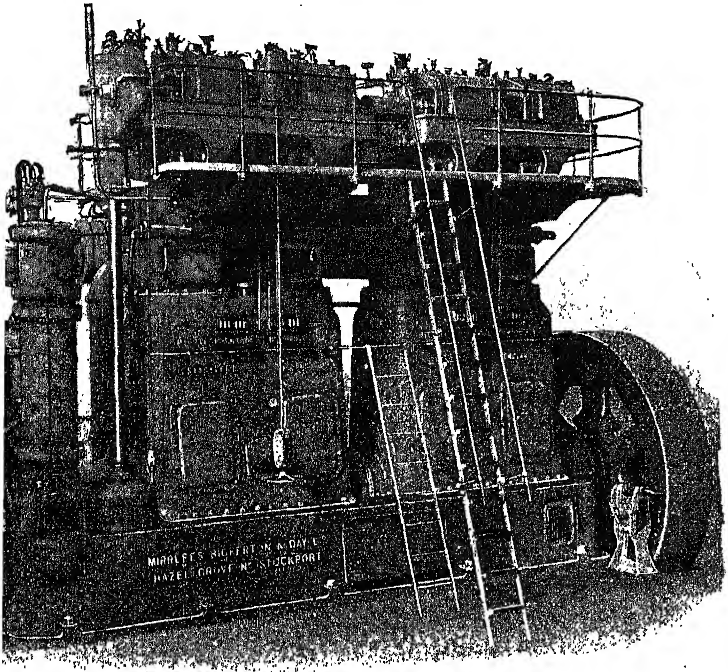


FIG. 129.

TABLE XC.

DATA *RE* FUEL OILS.

Class of fuel oil.	Specific gravity.	Flash point.	Average calorific value by bomb.
		deg. Fahr.	B.Th.U. per lb.
erican residuum	0·886	350	19,627
badoes	0·958	210	17,718
nco	0·936	285	18,831
ma	0·920	230	18,864
sian ostatki	0·956	308	19,440
as	0·945	244	19,242
st furnace oil	0·979	206	16,080
avy tar oil	1·084	218	16,050
le oil	0·875	288	18,217

A general calorific value of 18,000 to 19,500 B.Th.U. per lb. can be counted on in the case of the principal fuel oils. Other liquid fuels like blast furnace oil, and heavy tar oil obtained by the distillation of coal tar have a lower value ranging from 16,000 to 16,500 B.Th.U. per lb. The tar obtained as a by-product in the manufacture of carburetted water gas at gasworks has a similar calorific value and can be used in Diesel engines.

Fuel Consumption and Thermal Efficiency.—The thermal efficiency of Diesel engines at full load is practically constant over a wide range of sizes of units and is approximately as given in Table No. XCI. (Pfeiffer, "Journal, Institution of Electrical Engineers," England, Vol. 43, 1909.)

TABLE XCI.

DIESEL ENGINES: THERMO-DYNAMIC EFFICIENCY AT FULL LOAD.

Items.	Per cent.
Calorific value of fuel	100
Loss in exhaust, cooling, and radiation	55
I.H.P.	45
Loss: engine friction and air pump	11
B.H.P.	34
Generator loss at 91 per cent. efficiency	3
Efficiency of oil engine generator at full load	31

TABLE XCII.

GUARANTEES FOR A 600 B.H.P. DIESEL SET.

Engine load.	Efficiency of electric generator.	Fuel consumption.	
		Per B.H.P. hour.	Per K.W.H.
	per cent.	lbs.	lbs.
12·5 per cent. overload	93	0·40	0·58
Full load	93	0·40	0·58
Three-quarter load	92·5	0·42	0·61
Half load	92	0·47	0·69
Quarter load	88	0·66	1·01

Table No. XCII. sets out the guarantees for a 600 B.H.P. engine electric set operated on petroleum residue having a calorific value of 18,500 B.Th.U. per lb.

The results of an official test of a Diesel engine using fuel having a calorific value of 18,000 B.Th.U. per lb. are set out in Table No. XCIII.

TABLE XCIII.

OFFICIAL TEST OF DIESEL ENGINE.

Approximate load.	I.H.P. in diagram.	B.H.P.	Mechanical efficiency.	Fuel consumption. Total per hour.	Fuel consumption. Per B.H.P. hour.	Thermal efficiency.
			per cent.	lbs.	lbs.	per cent.
Full load	225·05	147·60	74·1	71·41	0·484	28·95
Three-quarter load	200·40	125·95	69	57·3	0·454	27·33
Half load	145·34	70·89	55·6	38·57	0·545	23·44
Quarter load	114·55	40·10	43	28·65	0·715	18·85

In the case of tests made at Kimberley, Wis., U.S.A., with a 225 B.H.P. engine direct coupled to a generator, the results set out in Table No. XCIV. were obtained.

TABLE XCIV.

RESULTS OF TESTS: 225 B.H.P. DIRECT COUPLED SET.

Load.		Fuel consumption.		Jacket water.				B.Th.U. per B.H.P. hour.	Thermal efficiency of engine.
B.H.P.	K.W.	Per B.P.H. hour.	Per K.W.H.	Average inlet temperature.	Average outlet temperature.	Per hour (total).	Per B H.P. hour.		
		lbs.	lbs.	deg. F.	deg. F.	gals.	gals.		per cent.
263·8	177·2	0·516	0·77	40·0	170·0	5306·0	20·1	10,041	25·3
249·7	167·7	0·464	0·69	38·8	180·0	3894·5	15·6	9,029	28·1
194·9	127·3	0·469	0·713	34·0	137·9	3324·0	17·1	9,127	27·8
133·7	84·8	0·493	0·778	34·0	135·5	2528·3	18·9	9,594	26·4
68·15	40·7	0·776	1·29	34·0	126·6	2033·5	29·5	15,103	16·8

As a last example, the results of tests with a 375 B.H.P.

"Mirrlees" Diesel engine of the crosshead type are set out in Table No. XCV.

TABLE XCV.

TESTS WITH 375 B.H.P. "MIRRLEES" DIESEL ENGINE.

Mean load.		Fuel consumption.	
B.H.P.	K.W.	Per B.H.P. hour.	Per K.W.H.
		lbs.	lbs.
359·1	244·2	0·412	0·606
268·5	183·3	0·424	0·621
178·4	120·8	0·460	0·681
89·1	60·2	0·648	0·959

From the above figures, it will be seen that the fuel consumption of Diesel engines of different sizes when operating at normal load ranges from 9000 to 7500 B.Th.U. per B.H.P. hour, the larger engines being somewhat more economical than the smaller ones. As contrasted with steam and gas-driven plants, no stand-by fuel losses are incurred in operating Diesel engines.

Cooling Water.—For average conditions of operation in temperate climates, such as that of Great Britain, an allowance of from 4 to 5 gallons of cooling water per B.H.P. hour with an outlet temperature not exceeding 180° Fahr. is sufficient for Diesel engines. Under adverse conditions, the requirements will be larger, and in the tropics where inlet temperatures up to 90° Fahr. or even higher may be experienced an allowance of 10 to 11 gallons per B.H.P. hour is usual.

The make-up water in temperate climates may be calculated at 2·5 per cent. of the total circulated.

Lubricating Oil.—The consumption of lubricating oil varies somewhat with the type of engine and is also affected by the condition in which it is maintained. For the larger engines of the enclosed type fitted with forced lubrication, the average consumption of lubricating oil may be taken at 1 per cent. of the quantity of fuel oil used at full load. For smaller engines of the open type, the corresponding average figure may be taken at from 1·5 to 2 per cent.

General Observations.—Although Diesel engines of relatively

large size are now being constructed in increasing numbers for marine work, the employment of prime movers of this type is at present restricted to power houses of small or medium size for the reasons stated at the commencement of this chapter. For such stations the use of Diesel engines is attended with a number of advantages in respect of reduced space and reduced cost of buildings owing to the simple character of the accessory plant required, as compared with that for a steam or gas engine power house, and to the smaller storage space required for the liquid fuel, and the ease with which the latter can be handled. Whereas a ton of coal requires from 42 to 45 cubic feet of storage space, a ton of fuel oil only requires about 39 cubic feet; moreover, on the basis of equal weights of fuel oil and coal, a Diesel plant at full load will give an output from 4 to 5 times larger than that of an equivalent steam plant under corresponding conditions, and from 2 to 3 times greater than that of an equivalent gas engine and gas producer plant. If the price of fuel oil exceeds that of coal in the above ratios, a Diesel plant can still compete on an equality with steam or gas-driven plant as far as fuel costs are concerned. Having regard, however, to the ever-increasing demand for fuel oil for marine purposes, boiler firing, etc., the question of a regular and adequate supply at a reasonably steady price is one which requires the fullest consideration of the designer when contemplating the installation of Diesel sets in a power house.

The economy of the oil engine depends upon a correct proportionment of the vaporized oil and the air admitted, and the permissible range of this proportion is very small for an oil fuel of given calorific value. If there be too little oil vapour and an excess of air, then the resultant mixture will cease to be inflammable. On the other hand, if too much oil vapour is admitted, then there will be insufficient oxygen present in the mixture to support complete combustion, with the result that unburnt gases will be exhausted and carbon deposited in the cylinder. In towns where compliance with smoke regulations is necessary, care must be taken always to work the oil engines above $\frac{1}{5}$ rated load, otherwise smoke will be emitted from the exhaust due to the imperfect combustion of the fuel.

CHAPTER IX

SOME PRACTICAL NOTES ON GENERATORS, MOTORS, BOOSTERS, TRANSFORMERS, ETC.

THIS work does not profess to deal with the design of generators, motors, etc., but only to give practical details of the kind needed by the designer of power houses, such as weights, spaces occupied, and so forth. A few practical notes and references are all that need be given under this section.

Typical Turbo Alternator.—A brief description may be given of the turbo alternator illustrated in Plate VIII., namely, a 5000 K.W. 25-cycle Willans-Dick-Kerr generator coupled to a steam turbine running at a speed of 750 R.P.M. It should be noted that the tendency is now towards higher speeds.

This plant has been taken merely as a type, and it is of course understood that there are many manufacturers who make similar machines of equal excellence.

The generator has a revolving field with salient poles, and further observations regarding rotors of this type are set out in a subsequent paragraph.

The frame of the stator is of cast iron, and the coils are built up on the solid system and drawn into the slots, being insulated with mica. The coils were tested to 25,000 volts at the works. The stator has six slots and eighteen conductors per pole per phase. Special ventilating ducts are provided in the frame and laminations, stiffening fingers being fixed on the outside of the laminations to obviate danger of vibration. The complete weight of the stator is 42 tons.

The rotor has four poles, and the body is built up of a central solid steel casting with salient poles, and cast under pressure. The central body is machined and bored out to a

diameter larger than that of the shaft. Two cross-shaped pieces which carry the rotor on the shaft are built up at each end of the central body, and are so arranged in reference to the shaft as to leave an ample space all round for ventilation. The rotor is pressed on to the shaft at about 100 tons pressure. The central body is provided radially with drilled passages which correspond to the air ducts in the laminated pole tips. These pole pieces are dovetailed into the central casting. Special end-pieces are also dovetailed into the casting to retain the laminated tips in position and at the same time to act as checks on the centrifugal forces acting on the spools. To guard against the centrifugal forces which tend to spread the coils, wedge-pieces are inserted between adjacent coils so as to press against them and also against the pole tips. The complete weight of the rotor is 20 tons, and the peripheral speed 10,000 feet per minute.

The field windings are built up of solid copper strips wound on edge, insulated between turns by paper and mica, and supported in a special copper spool with heavy insulated flanges. The spools after being formed and insulated are subjected to hydraulic pressure in the axial direction up to 50 per cent. in excess of that to which they would be subject from centrifugal stresses under normal working. As the copper winding bears flat on the insulation there is no danger of cutting. The spools are ultimately finished on the outside surfaces with a special varnish, both oil and water proof, giving a very hard and also a glazed surface.

The collector rings are made from a special grade of cast iron, fixed over a solid steel sleeve. They are of special construction so as to make it impossible for them to be subject to deformation under working conditions. The collector rings are shrunk hot over special micanite bushes built up directly on the steel shell of the ring.

The exciter is connected to the alternator shaft by a flexible coupling, and is carried in two spherically seated bearings. The excitation is 300 amperes at 125 volts at full load, or 37·5 K.W., i.e. 0·75 per cent. of the generator rated load.

The output of 5000 K.W. is calculated on a power factor

of 0·85 and the efficiency is 96·2 per cent. at full load at that power factor.

The commercial efficiencies, including friction, windage, and rheostatic losses, are as set out in Table No. XCVI.

TABLE XCVI.

COMMERCIAL EFFICIENCIES OF 5000 K.W. ALTERNATOR.

Power factor.	Commercial efficiencies at specified output.				
	7500 K.W	6250 K.W.	5000 K.W.	2500 K.W.	1250 K.W.
	per cent.	per cent.	per cent.	per cent.	per cent.
1·00	97·25	97	96·4	93·6	88·2
0·85	—	96·7	96·2	93·5	88·1

The generator can carry an overload for two hours of 6250 K.W. at a power factor of 0·85 at normal pressure and speed.

The temperature rise after working continuously for not less than 12 hours (with natural ventilation) is such that no part of either the stator, rotor, or exciter exceeds 70° Fahr. above the surrounding atmosphere.

Type of Rotor in Turbo Alternators.—On the whole, it is better for turbo alternators to be provided with rotors of the cylindrical type rather than of the salient pole type. The former type having the windings distributed in slots affords more cooling surface, and there is less magnetic leakage. Moreover, the winding space is more efficiently utilized, the salient pole type requiring to be filled in with supports to prevent distortion or slipping under the large centrifugal stresses set up at the high peripheral speeds when turbine driven. The cylindrical type of rotor can be also constructed with great mechanical strength, and with but little liability to get out of balance, an extremely important matter in high speed generators.

Stator Slot Windings.—From the brief description of a typical alternator given above, it will be noticed that there are only three conductors per slot, thereby reducing the voltage between neighbouring conductors to the reasonable limits of 366 volts. This is of importance in the design, and also in the

endurance of the machine, as it enables a proper factor of safety to be adopted in the slot insulation between neighbouring conductors. Hence the remark previously made that it is advisable in high-pressure transmission schemes to restrict the generator pressure to the reasonable standard of 6600 volts—an empirical figure, it is true, but one also reasonably practicable—and to step up this pressure to the line pressure by means of static transformers. The chances of brush discharge from the windings are thus reduced in practice to a negligible quantity.

Stator Slot Insulation.—The question of insulation is very important, especially for machines required to work in tropical or semi-tropical climates or in wet districts. The following specification for slot winding has been found by the Author to withstand these climates with success.

Each stator coil to be made up from bare copper strap one turn above the other and completely wound on a former. Each turn to be taped all over with unimpregnated No. 2 cotton tape. A sheet of mica about 10 to 15 mils. in thickness (consisting of mica splittings pasted on to Japanese paper with flexible mica varnish) to be interleaved between successive turns within the slot-length. The whole coil then to be taped with No. 2 tape, non-overlapping and impregnated *in vacuo* with a clear baking varnish and subsequently baked dry.

The ends of the coil outside of the slot then to be taped with three layers of Empire cloth (bias taped), each layer to be varnished with one coat of clear baking varnish and to be baked dry before the next layer is applied. The first of these three layers to extend right up to the point where the coil projects from the iron, and the two other layers to finish each 1 inch further out than the underlying one, so as to taper off.

The coil within the slot and for a length of 3 inches beyond each side to be served with a covering of pure Indian mica, $\frac{1}{10}$-inch in thickness, built up with shellac and pressed on hot. The whole of this mica tube then to be tightly enclosed in a close-fitting sheath of leatheroid and carefully coated with a thoroughly waterproof oil-resisting varnish. A trough of leatheroid treated with paraffin wax to be fitted in the slot as a further mechanical protection to the finished coil. The mica

covering to be tapered in thickness at the ends so as to correspond with the taper on the Empire cloth covering. The coil to be firmly held in position in the slot by a wedge of seasoned hornbeam.

The end portions of the coil then to receive three further tapings of Empire cloth, each overlapping the mica cell and reaching up to the point where the coil leaves the iron. Each layer to be well varnished.

A final taping of No. 2 cotton tape impregnated with a clear baking varnish to be then applied, after which it is to receive two coats of an approved air-drying varnish. The portions of the coil where the taping overlaps the mica cell to be tightly bound with a hard twine.

Field Coils.—The field coils to be former wound with rectangular section wire, double cotton covered and painted with electro enamel as the coil is wound on. One turn of $\frac{1}{4}$-inch rope, impregnated *in vacuo* with insulating varnish, to be fixed in the corners in the inside. The inside of the coil to be protected with two layers of $\frac{1}{32}$-inch leatheroid, both layers to be bent over in the straight parts of the coil so as to protect the top and bottom portions over the full width. A similar protection of four flanges of $\frac{1}{32}$-inch leatheroid to be placed at the top and bottom inside the brass flanges of the spool. The formed coil to be impregnated *in vacuo* with a clear baking varnish.

Insulating Material.—Insulating materials vary so much in quality that makers should be required to submit samples to the engineer for testing. As much care is needed in this as in testing the steel for the shaft. Permeability tests of the iron can well be left to the manufacturers, as their compliance with the salient tests of temperature rise, regulation and efficiency will govern the quality of the iron used. But insulating materials may pass the high-pressure test and heat runs of a set quite well, and yet because of their hygroscopic qualities may break down some time after the machine has been taken over. For this reason the Author advises that the engineer should insist on making independent tests to a rigid specification.

These materials may be broadly classified as follows :—

(A) Woven textures;

(B) Short fibrous material compressed in an unvarnished or otherwise untreated condition.

These should be made to pass the following laboratory tests; sensible and practical tests which have been adopted by Mr. W. P. Digby, who formerly assisted the Author in laboratory and testing work.

(1) *For A Class Materials.*—Insulation resistance to be not less than 100 megohms per square inch of surface, after 100 minutes' exposure in a saturated atmosphere at 75° C.; the increase in thickness of the sample after the above test and when measured by a micrometer not to exceed 1 per cent.; the increase in weight (also after the first test) when measured in a balance not to exceed 2½ per cent. of the original weight.

(2) *For B Class Materials.*—Insulation resistance to be not less than 20 megohms per square inch of surface after 100 minutes' exposure in a saturated atmosphere at 75° C.; increase of thickness at end of test not to exceed 5 per cent., and increase of weight not to exceed 5 per cent.

Insulating varnishes must also be tested, as a good deal depends on these. The varnishes should be free from moisture, acids, and alkalies, and a film, when dried, should be plastic and not brittle, of uniform thickness and resistant to or inert with both oils and acids. Cases are known where leaky glands on reciprocating sets have allowed oily vapour to be drawn in by the fan-like action of the generator; the oil has then condensed on the windings and broken down the insulation. Moreover, slight brush discharges in alternating current generators may be a cause of serious trouble through the formation of nitric acid.

A dry film 0·002 inch in thickness laid on a plate of very thin metal should not give any noticeable increase or decrease of weight after being kept for 2 hours at a temperature of 95° C. with free access of air. It must also be sufficiently plastic not to show any signs of cracking when the metal plate is bent inwards and outwards through a right angle around a bar ¼-inch in diameter.

Former wound coils should be used where possible, that is a coil the conductors of which are bent to shape in a jig, insulated

from one another and encased in the necessary slot insulation (which is usually moulded and pressed on) so as to be placed directly in the open slots without bending or straining the conductors, as explained fully on a former page.

Insulation Tests.—Each stator coil should be tested in slots (so as to represent the stator iron) with an alternating current pressure at least twice the normal rated pressure, for a period of one minute. For example, with a 6600 volt machine the testing pressure for one minute should be 15,000 volts.

Rotor windings, or field coils, should be tested at an alternating pressure of 1000 volts for a period of 5 minutes, in each case applied between the windings and the frame.

Staying of End Windings of Alternators.—The staying of the end windings of 3-phase machines should receive careful attention, for in the case of a short in the system outside, heavy magnetic pulls result on these windings and consequent severe mechanical stresses. These may cause not only deformation in the end windings themselves, but also exert heavy leverage on the slot windings with resultant damage to the insulation at the entrance to the slots. Spacing blocks between coils are usually made from gum-impregnated ash bound to the coils with hard twine.

Wave-form and Parallel Running.—There is another matter also requiring practical attention, viz. the easy parallel running of the various alternators. Care has therefore to be exercised when selecting the design of a machine to see that the wave-form is as nearly as possible a sine wave, and for this purpose oscillograph records should be taken by the engineer.

It is important, especially in these competitive days, to see that the iron in the machines is not unfairly reduced in weight, or that too high a flux-density is used with a consequent too narrow margin for steadiness in running. The copper can fairly well take care of itself, since the temperature guarantees will control the dimensions adopted.

Hunting is sometimes found in reciprocating engine-driven sets owing either to an insufficient fly-wheel effect, with a consequent cyclic irregularity, or to over-sensitive engine governors. This effect is almost unknown with turbo-driven sets.

Surging of current between alternators also sometimes happens, and is due either initially to hunting, or to an insufficient amount of iron in the stator or rotor. An extra amount of iron acts as a damper on the oscillations. A damping coil or copper grid embedded in the pole faces will have the same effect, and may be used; or else solid iron poles or cast-iron pole shoes, the latter providing an easy path for the eddy currents. These have the effect of damping down reactive currents which tend to make the machine unstable in operation.

Inherent Regulation.—The inherent regulation of generators is another matter requiring attention when selecting machines. This is, of course, the percentage by which the voltage of a generator rises, with constant speed and excitation, when the rated load is suddenly thrown off. Manufacturers supply characteristic curves with their tenders, from which both this and the inherent regulation for varying power factors can be at once deduced. On non-inductive loads this is usually restricted to 6 per cent.; and with a power factor of 0·8 to a maximum of 20 per cent. The makers of salient pole rotors claim that a better regulation is obtained with this type, and that heavier overloads may be got due to the greater weight of copper that can be carried on a rotor of given dimensions.

Excitation regulation is another detail which requires to be specified by the engineer or stated by the manufacturer. This is the percentage increase of voltage above that for no-load required to maintain the generator at its full-load rated output.

Efficiency.—In good practice the efficiency of a machine is now generally specified as in Table No. XCVII. according to the size.

TABLE XCVII.

EFFICIENCIES OF GENERATORS.

Power factor.	Efficiencies of generators at specified loads.				
	$1\frac{1}{4}$ load.	Full load.	$\frac{3}{4}$ load.	$\frac{1}{2}$ load.	$\frac{1}{4}$ load.
	per cent.	per cent.	per cent.	per cent.	per cent.
Unity	95·5 to 97	95·5 to 96·5	94·5 to 95·5	93 to 93·6	88·2 to 90
0·8	94·5 ,, 96·7	94·5 ,, 96·2	93·5 ,, 95	91·5 ,, 93·5	88

Heat Tests.—The temperature rise of any part of the generator after a run of twelve hours at full load at 0·8 power factor is usually specified not to exceed 39° C. (70° Fahr.) above that of the surrounding air when taken with a shielded mercury bulb thermometer encased in tinfoil, placed against any winding, or against the iron of the magnetic circuits.

The heat test on large machines is usually made at the maker's works by running each generator an open circuit, over-excited, until such time as the stator iron temperature is steady, which may be taken as the period when the increase in temperature does not exceed one-half a degree C. in one hour. The permissible temperature rise under this condition is generally specified not to exceed 30° C. (54° Fahr.), taken as above.

Balancing Rotors.—The accurate balancing of rotors is of great importance. This is usually effected by first obtaining a static balance on a pair of knife edges, and then by running up to a proof test speed about $\frac{1}{3}$ above normal speed in a special balancing machine. The two tests are essential, for while a rotor may have been built up with an accurate statical balance, displacement of parts may occur after running up to speed which will upset entirely the former accurate balance. A powerful couple may in this way be set up and cause excessive vibration.

Direct Current Turbo Generators.—For direct current turbo generators some manufacturers now exclusively use compensated windings, generally concentrated on the pole pieces, of the order of twice to $2\frac{1}{2}$ times the ampere turns on the armature. These have the effect of neutralizing any distortion of the flux by the armature, and they also provide a field to reduce sparking as the current in each particular coil is undergoing reversal, thus increasing the range of sparkless commutation. There is, however, a tendency to flash over owing to the excess field ampere turns, and it is now usual to adopt a combination of both compensating windings and intercalary poles.

Brushes and Commutators on Turbo Generators.—Some makers use brass wire brushes running on grooved commutators so as to increase the area of contact and to allow the brush to follow better any irregularities on the commutator. Others adopt radial commutators with the brushes arranged sideways,

so as to avoid jumping. Pneumatic holders for carbon brushes are also used.

Each has its advocates, but the radial type appears to be the best kind both mechanically and electrically.

The commutator hub should be cast with the armature spider, or so rigidly clamped to an extension that no relative movement between the two parts can take place.

The bars should be of hard drawn copper finished accurately to gauge, and insulated from each other with good amber mica milled carefully to a uniform thickness, and of such a quality as to wear evenly with the copper segments.

Armature Windings and Field Coils.—The armature windings should consist of rigid former-wound coils in one piece, without joint, embedded in and well insulated from rectangular slots in the armature core, held in position by hornbeam wedges, and capable of being easily removed and replaced. The core plates should be of soft annealed steel of high magnetic quality, and well insulated from each other. The windings should be wound from bare copper strap, each strap being taped with an overlapping layer of No. 2 cotton tape, the coil being then impregnated *in vacuo* with a clear baking varnish. The coil within the slot should be wound with so many turns (to suit the pressure) of pure manilla paper and mica interleaved between the copper straps. The whole coil should then be taped with an overlapping layer of No. 2 cotton on the ends (non-overlapping in the slot), and again vacuum impregnated. Equalizing rings should be placed at the back of the commutator.

Each coil should be tested at, say, 2000 volts alternating for one minute before being placed in position.

The pole pieces are better made of laminated steel with solid pole tips and should be accurately machined.

The field coils should be readily detachable, interchangeable and well ventilated. The connections between adjacent coils should be well secured to the rotor, connected by clamping sleeves and protected by insulating cases, for example of leatheroid.

Heat Tests for D.C. Generators.—Direct-current generators are usually specified to have a temperature rise not exceeding

50° C. (90° Fahr.) above the surrounding air after a run of six hours at rated load. The temperature is taken as mentioned under "Heat Tests" on p. 328.

Ventilation of Generators.—The ventilation of generators is important, and has a direct effect on the rating of the machine, especially in exacting climates or in plants running on a high load factor. In some cases a fan is fixed at each end of the rotor, the air being driven around the end windings of the stator and also through the ducts in the core plates and out at the top of the casing. This system is quite satisfactory for machines up to, say, 2000 K.V.A. For larger machines a separately driven fan should be provided, supplying air through trunks to the bedplate inlets and forcing it through both rotor and stator, so that large quantities of air of the lowest available temperature can be forced through the generators. Machines so ventilated are capable of developing heavier overloads than when self-ventilated only. Where coal dust has to be considered, as in the case of collieries, or in climates subject to dust storms, or in large cities, air filters are sometimes employed, the air supplied to the machines being thoroughly cleaned and cooled.

At the Dock Sud power house, Buenos Ayres, for example, the 7500 K.W. turbo generators are of the enclosed type with induced draught ventilation on Brown Boveri's system. Cold air entering through openings in the bedplate is blown by means of two fans through channels provided on the rotor and then through the stator, leaving the machine by an opening at the top of the casing. By means of this system of ventilation all parts of the machine are maintained at a uniform temperature, and equal expansion results. These generators are capable of carrying a 25 per cent. overload for half an hour, and the temperature rise on any part of the machine after 10 hours continuous run at rated load was guaranteed not to exceed 50° C. (90° Fahr.) above that of the surrounding atmosphere.

Specification of Materials.—Very great care has of course to be exercised in the specification of the materials used on rotors, and the following notes will be useful.

The peripheral speed of turbine-driven rotors is usually about 17,000 feet per minute, but speeds of 21,000 are also

adopted by manufacturers who claim an ample factor of safety.

Steel shafts should be machined down from heavy forgings of mild open-hearth acid steel with a tensile strength of from 34 tons to 37·5 tons per square inch, and an elastic limit from 20 to 22·5 tons, with an elongation not less than 26 per cent. in a 2-inch test length.

Steel binding wire should have a tensile strength of 112 tons per square inch, and a factor of safety of 3 taking into account both bending and tensile stresses.

Bronze binding wires should have a tensile strength of 54 tons per square inch, with a factor of safety of 3 taking into account both bending and tensile stresses.

Spiders for rotors should be strongly constructed and clean cast from a mixture of good grey close-grained pig iron. A test bar 3 feet 6 inches long and 2 inches by 1 inch in section cast from the same mixture, when placed on bearings 3 feet apart, should bear a test load of 30 cwt. suspended from the middle point without breaking, the deflection under this load being not less than $\frac{5}{16}$ inch.

The laminations for the stator core and poles should be of best soft annealed steel, having a low hysteresis constant and a high permeability, and free from burrs on the edges. The core plates should be well insulated from each other.

Pole pieces should be so designed as to permit of their easy removal with their field coils without dismantling any part of the stator. The pole tips should be so shaped as to distribute the flux in such a manner as to give practically a sine wave-form. Damping coils are sometimes required to improve parallel running, or other means may be adopted.

Collecting rings for revolving fields are usually turned from hard gun-metal shrunk on a cast-iron bush previously insulated with a moulded mica ring. The brush current density, if carbon brushes are used (as is general), should not exceed 40 amperes per square inch.

Main bearings should be lined with white metal, which is usually made up of the following proportions, viz. 14·8 parts of antimony, 24 parts tin, 61 parts lead, with a trace of copper.

Excitation.—In some cases a direct-driven exciter, complete with the main set and driven from its shaft, is selected; in others, separately driven exciters supply the whole plant. Overhung exciters should be fixed on a very substantial bracket or pedestal, so that there may be no vibration arising from any "whip" of the extended shaft. On the whole, a separate exciter to each set has recommendations, as simplifying the exciter cabling and reducing the risks of breakdown. Having regard, however, to the additional uses of independently driven exciters for the lighting of the power house and the supply of the auxiliary motors, these are of value in medium-size power houses when coupled with a battery to give greater security.

For larger plants, however (that is, for units of 5000 K.W. and upward), the condenser motors become so large that the total cost of the power house is sensibly increased if direct-current motors supplied from an independent source are applied, and it then becomes advisable to install polyphase motors. That being the case, it is better for an independent exciter to be fixed to or driven from each main generator.

Auxiliary Motors.—The auxiliary motors in power houses are required to drive condenser pumps, feed pumps, mechanical stokers, large and small fans, and so forth. The ratio of their capacity to that of the total plant installed amounts to some $2\frac{1}{2}$ or 3 per cent. In 3-phase plant it is, perhaps, more economical to fix 3-phase auxiliary motors, though a total failure of the supply may cause trouble with the condensers and turbines and loss of time in restarting the plant. With independent exciters and a reserve battery for excitation and lighting, greater security will therefore be obtained by installing direct-current motors. Practice varies, however; but as no greater cost is involved and greater security is obtained, there is much to be said for direct-current motors in power houses of medium size. If direct current is adopted, it is now customary to fix the standard pressure of 220 volts as being better applicable generally to excitation, lighting and auxiliary motors. Should 3-phase motors be determined upon, then a standard pressure of 415 volts between phases is usually selected, the motors being supplied through step-down transformers.

Variable speed motors are often required for mechanical draught and for air or feed pumps. In the case of large direct-current motors, say for driving large fans, variation of speed can be effectively secured by adopting a double-wound armature and a series-parallel control. In the case of polyphase motors, speed variation within a strictly limited range can be obtained by the use of rotor resistances.

Nothing very much is required to be said here about the construction of motors, except that polyphase motors below 10 H.P. may be supplied with squirrel-cage rotors, while those above 10 H.P. should be of the slip-ring type so as to reduce the starting current.

From the nature of their work, motors are generally to be rated as "continuously working," and they should be specified to run at rated load for six hours without the rise of temperature exceeding 40° C. (72° Fahr.) above the surrounding atmosphere. They should also be capable of a 50 per cent. overload for 30 minutes without a rise of temperature exceeding 50° C. (90° Fahr.).

It is better to have motors of the enclosed type in the boiler house, and of the protected type elsewhere. Interchangeability of parts should be insisted on, as this will reduce the number of spare parts carried. The number of sizes of motors themselves should also be reduced to a minimum within reasonable limits, thus reducing the number of spare armatures or rotors required. Automatic lubrication is of course always provided.

It may be well to state here, rather than under Switchgear, that the Author has found it advisable, in a power house lay-out, to control all motor circuits from one main (auxiliary motor) board. Cables are taken therefrom to the various motors, each of which has its separate switch and set of fuses (or an auto-transformer or starting switch, either of the rheostatic or tramway controller type in the case of polyphase motors).

Boosters.—Where a battery is adopted, a motor-driven booster is indispensable. The object of this machine is of course to compensate for the variation of voltage between the extremes of charge and discharge, and to enable a minimum number of cells to be installed. Care must be exercised to see that such a

machine is amply big enough to take the larger current from the battery on emergency (short-time) discharges. "Milking" boosters are also required so as to doctor a weak cell. Series boosters are sometimes adopted in direct-current plants to compensate for the loss on long feeders, and are cheaper in some cases than the extra amount of copper otherwise required in the feeder. They may obviate the necessity for duplicate bus bars on the main switchboard, and also the running of two sets of machines at plant load factors lower than are obtained when the whole supply is grouped on one bar.

Battery boosters may be classed as under :—

1. Simple hand-regulated shunt boosters.
2. Constant current, non-reversible, automatic boosters.
3. Differential, reversible, automatic boosters.

Hand-regulated Boosters.—This type is not to be recommended except for small power houses where the attendant is continually on the switchboard and is only lightly worked. The function of this type of booster is to compensate for the difference in voltage between the bus bars and the increasing voltage of the battery during charge. The voltage range is equivalent to the number of cells in series multiplied by 0·7 volt (i.e. the difference between charge and discharge voltage of a cell, 2·55 and 1·85 volts respectively).

By the use of a two-way switch on the board, the booster can be used for discharging the battery and to compensate for the difference between the bus bar voltage and the diminishing voltage of the battery as it is discharged to its minimum limit. The booster must therefore be able to carry the maximum battery current (at a one-hour rate) for one hour and an emergency current of 50 per cent. above one-hour rate for several minutes, within the usual guaranteed temperature limits.

Non-reversible Automatic Boosters.—The non-reversible automatic booster is used for general supply work where the load fluctuates rapidly, and enables the battery automatically to follow the variations in the external load and to keep the machines on circuit on constant load. It is compound wound, with a series field wound in opposition to a stronger shunt field,

the line current passing in series through the former and the booster armature.

Reversible Automatic Booster.—The reversible booster has its armature in series with the battery (both being in parallel to the external line) and the series coil in series with the line, the shunt being of course in parallel to the line. It thus carries current in both directions, passing the maximum battery current through its armature, the maximum voltage being coincident with the maximum output. This type of booster is used for traction purposes in situations where the external load is large, and where the battery charge and discharge rates are moderate,

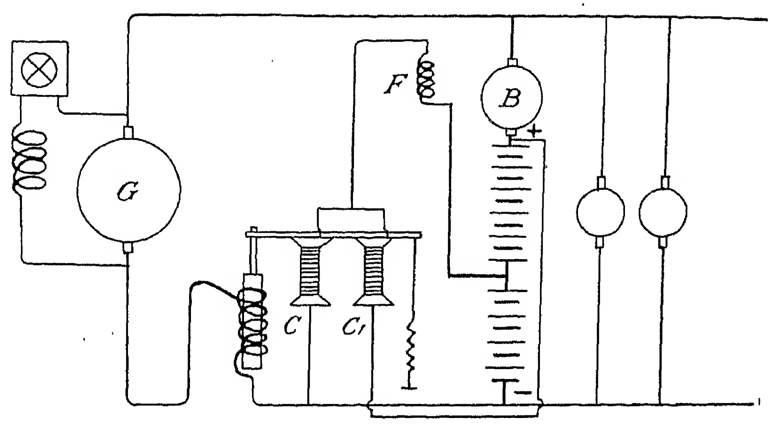


FIG. 130.

and where the voltage must be maintained during any increase of external load. There are several variations in the applications of automatic boosters, and the Entz booster may be described as a type.

The diagram of connections is shown in Fig. 130. The booster field winding F is connected at one end to the middle point of the battery, and at the other to the upper contacts of two carbon resistances C and C_1. The lower end of the carbon resistance C is connected to the negative side of the battery, and the corresponding end of C_1 is connected to the positive end of the battery. If the two resistances are equal, the potential at their common connection to one end of the field winding F is

equal to one half the total drop across the battery. As the other end of the field is at the same potential as the middle point of the battery, no current will flow through the winding F. When the resistances of the carbon piles CC_1 become unequal on account of the movement of the pressure lever which rests on them, current flows in one or other direction through the field coil F, and the booster comes into operation. The ends of the pressure lever are controlled respectively by a magnet in series with the generator and by an opposing spring. When the load is normal, the spring pull is adjusted so as to be just equal to the magnet pull, and the resistances of C and C_1 are thus equal. When the external load varies, a small but proportional variation in the magnet pull changes the relative resistances of the carbon piles C and C_1, and the booster field is thus energized so as to produce a booster pressure, causing the battery either to charge or discharge.

The following example may be cited to indicate the cost of reversible automatic boosters.

A booster guaranteed to meet the following conditions:—

(*a*) 1000 amperes from 0-100 volts continuously,
(*b*) 630 ,, ,, 0-200 ,, ,,
(*c*) 1600 ,, ,, 0-120 ,, on emergency for three minutes,

would have cost £825 before the war, or £6·5 per K.W. normal rating, and £4·3 per K.W. overload rating.

Balancing Transformers.—Balancing transformers are required in direct-current power plants supplying a 3-wire system so as to compensate for want of balance between the current in the + and − sides of the middle wire. These consist simply of a motor connected across the outers and driving two small shunt-wound generators all on one shaft, each generator being connected to its own side of the 3-wire system. To determine the size of the balancer, the greatest possible difference between the currents in the outer conductors at any one time must be estimated. As a matter of practice, even in quite large systems, an out-of-balance current of 250 amperes is an extreme figure, since all but the smallest motors on the supply system are

connected across the outers, while the lighting loads equate out in a remarkable degree. A battery in such systems is also a standby for balancing purposes.

Portable "Blowers".—Portable motor blowers are necessary for removing dust from windings, etc. They should deliver air at a pressure of about 30 lb. per square inch, so that internal windings can be cleared of dust without difficulty. It has sometimes been said that pressure cleaners of this kind only blow the dust from one spot for it to settle in another. The Author has not found this so in practice, and the machines are most useful and efficient. The alternative vacuum cleaners, it is said, have the disadvantage of sucking away some of the fibrous material of the insulating layers as well as the dust, though this criticism can hardly be said to be a fair one. One or other of these dust removers is, however, a useful auxiliary.

Static Transformers.—Transformers in alternating current power houses are required for lighting or auxiliary motors, as well as for stepping up the bar pressure to line pressure in special cases.

Three-phase oil-cooled transformers are usually used, the primary being either Δ or star wound, and the secondary star wound. For auxiliary motors the secondary pressure between phases is usually 415 volts, and for power house lighting 220 volts.

Three classes are recognized by the British Engineering Standards Association, viz. :—

(1) Air cooled by natural draught.

(2) Oil cooled by immersion.

(3) Artificially cooled, including both types as above.

There are also, of course, water-cased transformers which are sometimes used for step-up purposes, and in large sizes.

The standard sizes made—i.e. the loads at which the transformers will work continuously, while conforming to the standard tests given below—are :

5, 7½, 10, 15, 20, 30, 40, 50, 75, 100, 150, 200, 250, 300, 400, and 500 K.V.A.

The highest mean temperature permissible for types in which linen, cotton, paper and its preparations, micanite,

or similar insulating materials are employed, is 176° Fahr. (80° C.).

It is unnecessary, in this work, to say much more on this head, as one is not dealing with transformer design, but rather with the useful application of them in power houses. It will suffice to say that the load should be specified in Kilovolt-amperes; also that each transformer should be capable of working continuously at rated load with a temperature never exceeding 40° C. (72° Fahr.) above the surrounding atmosphere; and for three hours at 25 per cent. overload without a greater temperature difference than 50° C. (90° Fahr.). The temperature rise should be measured by a thermo-couple placed in the oil against the core.

Each transformer should be tested between the H.P. and L.P. windings, and between the L.P. windings and frame, at twice the working voltage for a period of fifteen minutes.

The efficiencies of transformers are generally as given in Table No. XCVIII., and are calculated from separate measurements of core and copper losses at a temperature of 60° C. (108° F.).

TABLE XCVIII.

EFFICIENCIES OF STATIC TRANSFORMERS.

Power factor.	Efficiencies at specified loads.				
	25 per cent. overload.	Rated load.	¾ load.	½ load.	¼ load.
	per cent.	per cent.	per cent.	per cent.	per cent.
1·0	98	98·1	98·1	97·8	96·5
0·8	97·5	97·6	97·6	97·2	95·6

The transformer should be fitted with radiating gills or corrugations to give effective radiation of heat, with eye-bolts for lifting, and sometimes rollers, with outside shielded terminals, and with oil-level indicators and cocks.

Low tension secondary tappings will be found useful so that the voltage may be varied from time to time, according to the ruling H.T. bar voltage at the main switchboard.

The oil must be carefully chosen, and must be free from

moisture, acids, alkalies, and sulphur compounds. It should have a high dielectric strength, and a flash point of not less than about 180° C., as mentioned in the next chapter (p. 368).

Table No. XCIX. sets out the leading dimensions, weights, etc., of standard sizes of transformers for 50 ∽.

TABLE XCIX.

PARTICULARS OF STANDARD STATIC TRANSFORMERS.

Output K.V.A.	Quantity of oil.	Approximate net weight.	Dimensions. Height.	Dimensions. Width.	Dimensions. Length.
	gallons.	lbs.	ft. ins.	ft. ins.	ft. ins.
2	3	195	1 5	0 7	1 4
5	7·5	495	2 0	0 9¾	1 7
7·5	7	550	2 5	0 10½	1 9½
10	18	750	2 5	0 10½	1 9½
15	27	1000	2 11	1 5½	2 4
20	26	1060	3 5	1 9	2 3
25	35	1280	3 5	1 9	2 3
30	34	1350	3 7	1 9	2 4
37·5	40	1470	3 7	1 9	2 4
50	48	1600	4 0	1 10	2 5

Transformers varied in cost from about £2 per K.V.A. for sizes up to 10 K.V.A. to £0·75 per K.V.A. for sizes of 250 K.V.A. output, and to £0·64 per K.V.A. for sizes of 500 K.V.A. These, of course, are pre-war figures.

In cases of difficult transportation, 3-phase transformers may, with advantage, be replaced by three single-phase transformers so as to reduce the weight of individual pieces to be carried.

Batteries.—In alternating current power houses, the battery is useful as a reserve for excitation and for power house lighting purposes. In direct-current plant batteries are useful for reserve purposes, and incidentally for balancing the loads on a 3-wire system, and are sometimes of very large output. For traction purposes, with a very fluctuating load on the generator, they are often a great economy. Even in a general supply system, where 3-phase energy is transmitted to substations and there converted to direct current for distribution, batteries play

a most useful part, not only in securing a larger measure of safety, but in giving a resultant economy by improving the load factor. The Planté plate is now practically universally used, and no other elements but lead and its oxides have yet been found commercially practicable for station work. Great commercial progress, however, has been made in recent years in the application of batteries to electrical supply on a large scale, and in reducing the initial cost and cost of maintenance, as well as by improving the efficiency and practical reliability of the cell.

Within usual rate limits, from 0·5 to 0·8 oz. of spongy lead, and from 0·53 to 0·86 oz. of metallic lead changed to peroxide, are required in negative and positive plates respectively to give a discharge of one ampere-hour.

The storage capacity of batteries depends, of course, on the rate of discharge and the temperature, besides being dependent on the number, size and character of the plates. The effect of *rate of discharge* in Planté plates is shown in Table No. C.

TABLE C.

DISCHARGE OF PLANTÉ CELLS.

Time of discharge in hours.	Percentage of capacity at 8 hours' rate.
	per cent.
8	100
6	96
4	80
2	60
1	56

As a datum for Table No. C. it may generally be taken that with an 8 hour discharge and at a temperature of 60° Fahr., from 40 to 60 amperes can be obtained per square foot of *positive* plate surface (i.e. the number of positive plates in parallel in one cell × breadth × height × 2).

The energy output in watts is usually about 7 watts per pound. The charge and discharge rate per square foot of *positive* plate under normal working conditions may be taken at 10 amperes.

Planté plates are now wholly used for heavy power house work, the active materials being of course formed out of and on the surfaces of the lead plates themselves. As the electrolytic action on the active material rarely penetrates to a greater depth than $\frac{1}{16}$ inch, the plates are made up of lead grids subdivided in such a way as to give a maximum working surface in any given size of plate.

Particular care must be taken with batteries to get pure sulphuric acid made from sulphur and not from pyrites. The latter, of course, contains iron, and acid made from it contains traces of iron. The electrolyte must be free from iron, or arsenic, copper, chlorine, nitrates, mercury, acetic acid, selenium, and other chemicals, slight traces of which would be injurious to the working of the battery and to the life of the plates. Commercially pure acid with a sp. gr. of 1·84 should therefore be obtained, corresponding to a strength of 97 per cent. The engineer should insist on a certified analysis being supplied, especially for the first setting up.

The Author usually specifies that not more than the following percentages shall be found on analysis, viz. :—

Iron, 0·005 per cent.

Chlorine, 0·002 per cent.

Nitrogen (in any form), 0·005 per cent.

Particular care must also be taken with the water used to make up the electrolyte, not only when first setting up the cells, but also afterwards. It is better to use distilled water, and with large batteries a distilling plant is a necessary auxiliary to be installed. For large batteries the Author thinks it would be well to fix circulating arrangements, so that the heavier layers of electrolyte which tend to collect in the bottoms of the cells may be circulated from time to time with the overlying lighter layers. "Gassing" the cells, while causing a fair circulation, does not necessarily bring up the denser electrolyte from the bottom layer. What has to be aimed at is a uniform density of electrolyte throughout the cell, so that a uniform discharge rate per unit area of plate may result. The resistance is affected not only by the density of the electrolyte but also by its temperature. The density decreases with the discharge and also

with an increase of temperature, the variation per degree Fahrenheit amounting to 0·0032.

Plates deteriorate rapidly if worked at temperatures above 100° Fahr., which should be the maximum temperature permissible. In hot climates, therefore, it is necessary to take special precautions for the ventilation of the battery house and to screen the roof from direct absorption of the sun's rays.

The efficiency of cells expressed in ampere hours is 90 per cent.; and expressed as a percentage of energy output (taken at a normal 4-hour discharge) to input it ranges from 75 per cent. to 80 per cent.

Wooden tanks (teak is preferable) lined with lead autogenously welded at the joints are invariably adopted in power house practice, the wood being dovetailed and pinned together with antimony-lead dowels. The lead sheeting should be turned well over the edges of the wood box, so as to prevent the acid creeping between the lining and the box. Solid lead boxes strengthened with antimony-lead ribs are also supplied. These are somewhat more costly than lead-lined wood boxes. The respective plates of each cell and its neighbour are welded up to a lead bus bar fixed between them. Glass tube separators between the plates are best; they enable easier inspection of the plates with a special lamp, for scale, etc., and permit a freer circulation of the electrolyte.

The cells are carried on heavy insulators fixed either directly on the battery house floor or on H joists carefully coated (and maintained) with anti-acid enamel.

Table No. CI. gives particulars of typical sets of cells suitable for power house work and for substations. Of course, very much larger (and smaller) sets are made, and the designer can obtain particulars of these from any of the well-known manufacturers.

It is not relevant to the objects of this book to enter into the question of the chemical theory or practical treatment of the battery, except so far as to recommend the provision of the necessary equipment to enable the staff to maintain the battery properly.

Certain of the cells will lag behind others from time to time

and become "sick". To meet this trouble, it is necessary to provide "milking boosters" which can be attached to any sick cell either to give it an increased charge after the remainder of the battery has been fully charged, or to assist it in parallel during the period of discharge. These auxiliaries are absolutely necessary. In a large battery equipment, the Author provides over each line of cells two bare trolley wires suspended on insulators and strained at both ends on shackles. To each pair of these conductors a milking booster (fixed in an annexe to the battery house and complete with its auxiliary switchboard) supplies current which is available for any cell (or two cells in series). Generally speaking, one "milker" to each line is quite sufficient. For smaller batteries an equipment of two milkers only is quite enough.

TABLE CI.

HIGH WORKING RATE CELLS.

No. of plates.	Ampere hours.	Working rate. Discharge.		Working rate. Charge.	Weight of cell complete with acid.	Gallons of dilute acid.	Dimension of cell. Length.	Dimension of cell. Width.	Dimension of cell. Height.
		hours.	amperes.	amperes.	lbs.		ins.	ins.	ins.
17	1314	3	438	480	1100	35	21	$23\frac{3}{4}$	$38\frac{1}{2}$
	1128	2	564						
	943	1	943						
21	1644	3	548	600	1300	43	25	$23\frac{3}{4}$	$38\frac{1}{2}$
	1410	2	705						
	1178	1	1178						
25	1971	3	657	720	1510	51	29	$23\frac{3}{4}$	$38\frac{1}{2}$
	1692	2	846						
	1414	1	1414						
29	2301	3	767	840	1720	59	33	$23\frac{3}{4}$	$38\frac{1}{2}$
	1976	2	988						
	1649	1	1649						
33	2628	3	876	960	1940	67	37	$23\frac{3}{4}$	$38\frac{1}{2}$
	2258	2	1129						
	1885	1	1885						
37	2958	3	986	1080	2150	74	41	$23\frac{3}{4}$	$38\frac{1}{2}$
	2539	2	1270						
	2121	1	2121						
41	3285	3	1095	1200	2360	82	45	$23\frac{3}{4}$	$38\frac{1}{2}$
	2822	2	1411						
	2356	1	2356						
45	3615	3	1205	1320	2570	90	49	$23\frac{3}{4}$	$38\frac{1}{2}$
	3103	2	1552						
	2592	1	2592						

The old method of regulating end cells of a battery has quite gone out. For heavy discharges, the switch as well as the copper connections from each regulating cell were very cumbersome and expensive; moreover, the rate of depreciation on the end cells, which were not worked so much as the others and tended to become overcharged and "fallow," was very high.

The regulation of a battery voltage to suit the bar or line voltages is now always effected by a battery booster. The reader is referred for further particulars to the paragraphs on battery boosters (*ante*).

The battery should be provided not only with hydrometers and thermometers, but also with a recording voltmeter, which will prove a useful indicator to the power house superintendent as to the use or misuse of the battery.

In laying out the battery and designing the battery room, double tier stands must be avoided. Cells should be arranged on one tier only, so as to be easily inspected and handled. It is customary to support cells on very large porcelain cup insulators with oil, so as completely to insulate the cell from earth.

The battery room floor must be designed to carry a heavy concentrated weight, reaching as high as $1\frac{1}{2}$ cwts. per square foot (excluding weight of floor). If on the ground level, blue Staffordshire stable paving bricks cannot be beaten, as they are vitreous and acid resisting, checkered on the face so that spilt acid or drip from condensation drains away clear of the tread of the floor, and they can be laid in neat courses with thin (cement) joints. They should always be laid with a good gradient, usually $\frac{1}{100}$ to gullies, for enabling the floor to be readily washed down and to dry quickly.

The walls are best lined with glazed brick, and very adequate ventilation of the room should be provided so as to get rid of the acid fumes. An annexe screened from the actual battery room should be provided to house the milking boosters and auxiliary switchboards. As stated before, the milking leads are best provided by stretching two trolley wires, to which faulty cells can be connected, lengthwise over each line of cells fed by the milking booster.

There should be ample storage room for acid, and in some

cases separate accommodation for a water-distilling plant and storage tank.

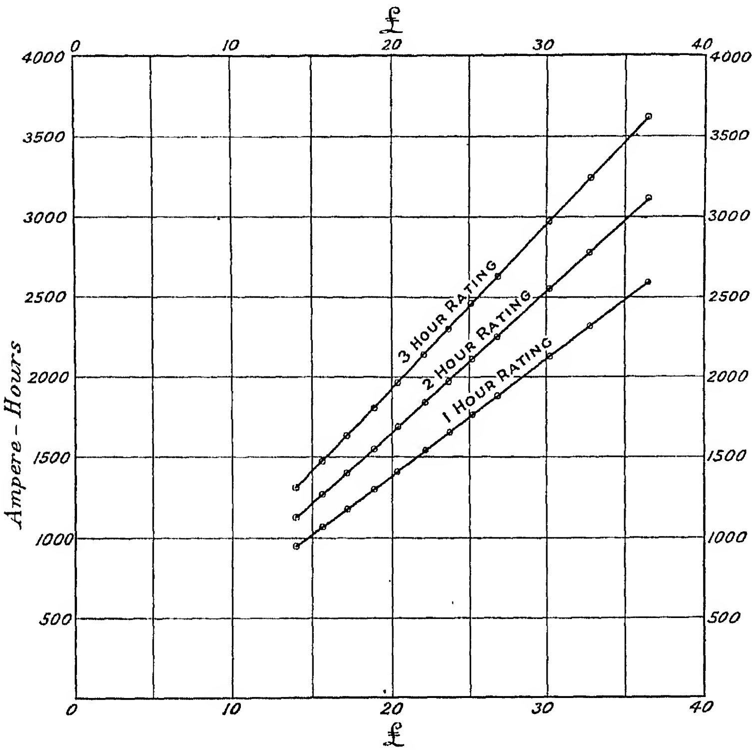


Fig. 131.

Approximate pre-war capital costs of batteries for various discharge rates are given in Fig. 131.

CHAPTER X

SWITCHGEAR

It is a comparatively easy matter to lay out the mechanical installation in a power house in a simple and straightforward manner. With adequate attention given to the pipe arrangements, the general mechanical design does not offer any great difficulties to the initiated. It is when one comes to the switching details that one not infrequently finds a careless arrangement of undue complexity, and also a disregard of the calls upon the unfortunate engineers who have to control and run the power house subsequently. The switchgear is really the nerve centre of the system. It must be capable of providing adequate control of the generators and the feeders or transmission lines, as well for ordinary working as for emergencies, and must be designed with due regard to further extensions and developments of the system. It requires also to be simple in character, as free as is humanly possible from risks of fire, short circuits, "earths," and lightning strokes, and safe in operation to the attendant and for inspection and cleaning.

Essentials in Switchboard Design.—The designer must bear in mind the following essentials in a good switchboard layout:—

(*a*) Simplicity, with a due regard to adequate protection, is a mark of good design.

(*b*) All parts should be readily accessible, but high-pressure parts to authorized persons only.

(*c*) The instruments, switch parts, straps, plugs, relays, etc., should (as far as practicable) be standardized and interchangeable.

(*d*) The whole of the switchboard should be fireproof. Bare

connections should be used wherever possible, and not india-rubber covered cables unless the latter are run in steel conduit. For high potential leads, etc , where insulation is necessary and conduit not used, then fireproof coverings should be employed.

(*e*) The conductors, switch contacts, etc., must be so designed as to carry their rated currents without overheating.

(*f*) The assembly of the panels, lay-out of switch cells, etc., should be symmetrical.

(*g*) A breakdown on one section of the board should not cause any dislocation in another part, and should only affect the generator or feeder connected to it.

(*h*) So far as possible the switchgear should be "fool proof," i.e. wrong connections, such as putting in a wrong switch, should be impossible without some warning to the operator.

(*i*) The design and position of the board and the component operating panels and apparatus should allow of adequate extension along pre-arranged standard lines.

Power house switchgear will here be subdivided broadly into three classes: (*a*) alternating current high pressure; (*b*) direct current medium pressure, which will also include tramways supply; and (*c*) auxiliary switchboards.

High-pressure Alternating Current Switchgear.—The following notes refer more particularly to 3-phase switchgear, but also apply, almost entirely, to switchgear for single-phase systems.

High-pressure switchgear may be conveniently classed into (*a*) remote control, and (*b*) direct control. In both cases the operating board is wholly low pressure, and the high-pressure parts are screened from the operator.

Remote Control H.T. Boards.—Taking first the remote controlled type, the oil-break switches, main bus bars, isolating links, etc., are right away from the operating panels. The latter can therefore be placed wherever the operator can most efficiently control the plant, and the apparatus may be in an annexe to the main building if desired.

The operating panels can be of the following kinds: (*a*) the vertical type, as shown in Fig. 132; (*b*) the bench type, as shown in Fig. 133, when the panels are slightly inclined (this

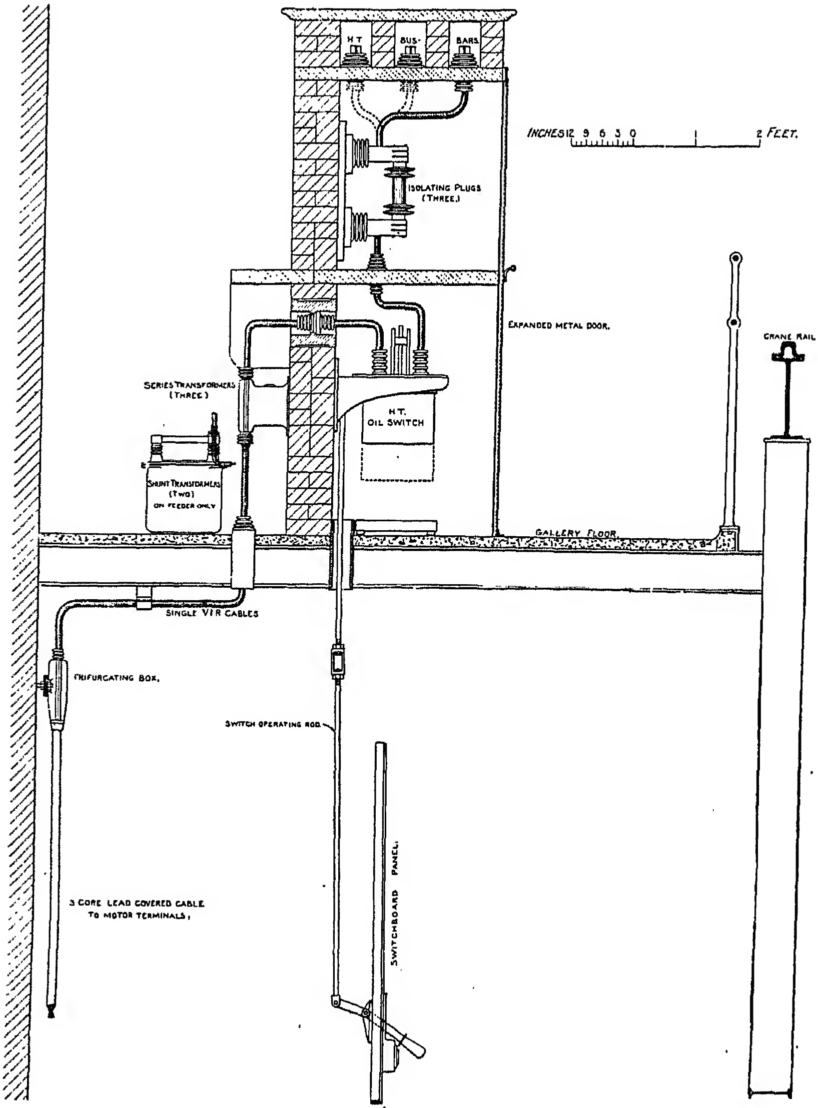

H.T. BUS- BARS
INCHES 12 9 6 3 0 1 2 FEET.
ISOLATING PLUGS (THREE.)
EXPANDED METAL DOOR.
CRANE RAIL
SERIES TRANSFORMERS (THREE)
H.T. OIL SWITCH
SHUNT TRANSFORMERS (TWO) ON FEEDER ONLY
GALLERY FLOOR
SINGLE V.I.R. CABLES
TRIFURCATING BOX.
SWITCH OPERATING ROD
SWITCHBOARD PANEL
3 CORE LEAD COVERED CABLE TO MOTOR TERMINALS.

FIG. 132.

figure shows a board made to the Author's specification for a 6600-volt 3-phase power house); or (*c*) separate pedestals of the

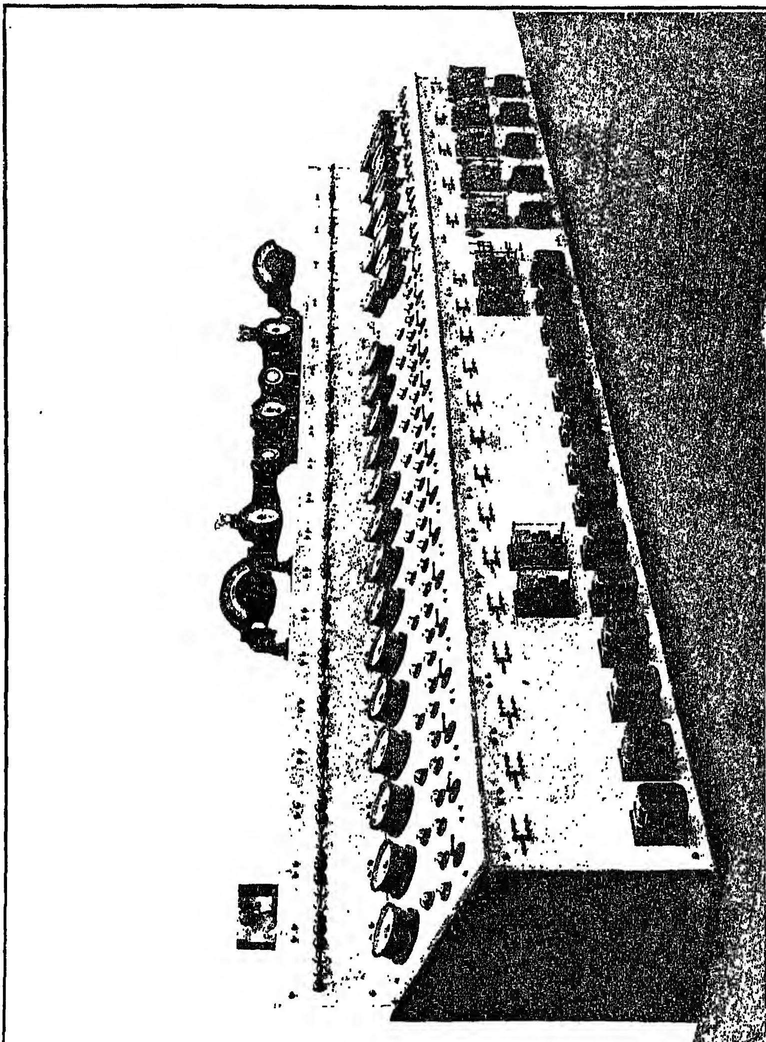


Fig. 133.

ironclad type, one to each generator or transmission line, as shown in Fig. 134.

The adoption of either of the two former is really a matter of choice, and is partly determined by the available space or position. Each type is applicable to power houses of moderate

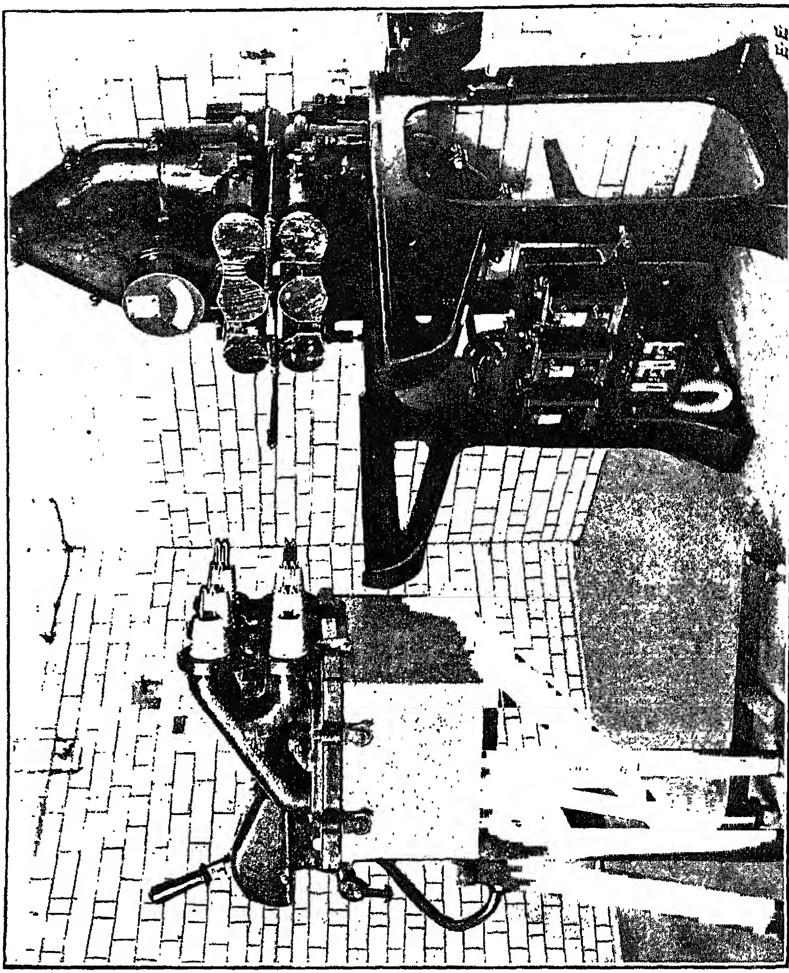


Fig. 134.

size. The arrangement shown in Fig. 132, for example, was designed for a traction substation for the L.C.C. tramways, and represents as simple and effective a type as can be adopted. The operating panels are on the machine floor level, and the

H.T. switchgear for controlling the 3-phase supply at a pressure of 6600 volts between phases is in cubicles in the gallery immediately above. The design is characterized by accessibility to parts and by safety of operation, inspection, and cleaning.

The pedestal or ironclad type of panel has some advantages for very large units, for example in bulk supply stations, whether steam driven or hydroelectric.

Plate No. IX. shows a typical diagram of the remote electrical control of oil-break switches. It will be seen that automatically operated red and green lamps are provided, which show respectively whether the control switch (and therefore the oil-break switch) is closed or open. The pilot circuits are usually worked at a pressure of 110-125 volts, and are supplied from a small auxiliary battery, or from some of the cells of a main battery. The control switch on the operating panel governs the actuation of the remote oil-break switch through the medium either of a powerful solenoid, or of a motor which compresses a spring on the main switch.

Greenwich Power House Switchgear.—An example of a remote controlled power station switchboard is shown in Plates Nos. X. and XI., and in Fig. 135, which illustrate Westinghouse switchgear installed in the Greenwich power house. The total output arranged for is 34,000 K.V.A. normal rating, or 42,500 K.V.A. on emergency, the maximum load being 30,000 K.W. Following out the diagram shown in Plate No. X., it will be seen that there are eight generator circuits and thirty-two feeder circuits arranged in eight sections. A 3-core cable is brought from each generator to a trifurcating box (shown at the bottom of the diagram) whence all three separate tails are taken, each passing through its isolating link and instrument series transformer to the oil-break switch. On the other side of the switch are further links, enabling the generator switch to be isolated. The connection there joins on to the main bus bar (but not directly, as is explained below), after which come further links, the sectional switch, further isolating links, and then the sectional bus bars.

Sectional H.T. Bus Bars.—Each set of sectional bars controls four feeders. Starting from the bus bars, each feeder has

isolating links, a feeder oil-break switch, instrument series transformers, and further isolating links, the feeder 3-core cable

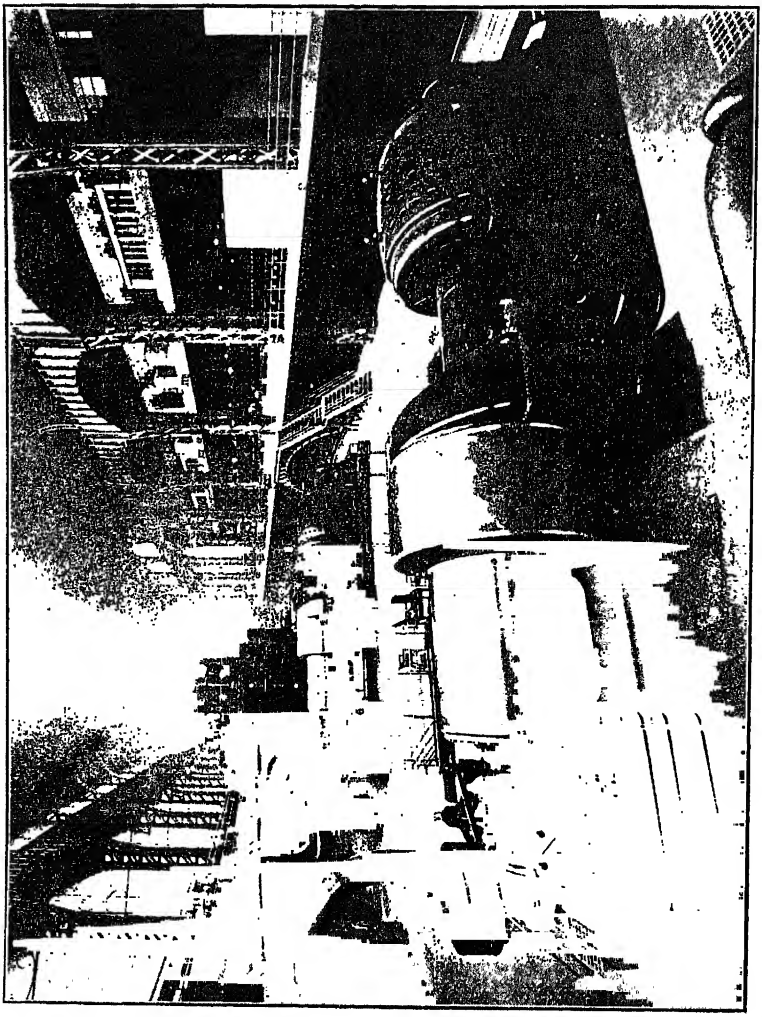


Fig. 135.

ending in a trifurcating box. Spark gaps are fitted, as shown in the diagram, to each phase of each feeder.

A further protection against any general breakdown will be noticed in the diagram (Plate No. X.). Each generator line

and corresponding sectional bus bar represents one complete unit. In normal working the generators and feeders are all paralleled on the main bus bars through isolating main bus-bar links. Thus, should any accident arise to the main bars, or to the synchronizing gear, each generator can be run independently of the others directly on its own sectional bars.

The main bars are also divided into two sections by a disconnecting switch, but are normally run interconnected.

Switch Galleries.—Plates Nos. XII. and XIII. show plans of and sections through the lower and upper galleries respectively.

The lower gallery contains the control boards, which face the engine-room, the instrument assembly boards, and the instrument transformers (three series and two shunts to each feeder), the latter being carried on brackets built out from the wall. The generator and feeder isolating links are also in the lower gallery and are mounted on insulators built into the wall of the power house.

The upper gallery accommodates the oil-break switches, which are contained within glazed brick cubicles, their own isolating links, the bus bars and the spark gaps.

Lead-covered 3-core cable is used wherever possible for connections between the various high-pressure parts.

A reverse current relay is fitted on each generator switch and a time limit overload relay on each feeder switch. The spark gaps discharge to a common earthing system, as shown in Plate No. X., consisting of three $\frac{19}{12}$ bare copper cables connected in three places to the circulating pipes which terminate in the river.

Synchronizing Gear.—In addition to the synchronizing gear in the lower switch gallery, there is a synchroscope fixed near the main stop valve of each steam set and connected in parallel with the other synchronizing gear when required. The driver can thus bring his set into synchronism with the other running sets by means of his synchroscope without having to depend upon signals from the switch gallery.

Engine-room Signals.—A simple set of signals is fitted between the operating gallery and engine-rooms. Two large illuminated telegraph boards are fixed and worked from the

control desk, so that the number of the machine and the signals "Slow," "Run up," "On load," "Reduce," and "Stop," can be shown as required.

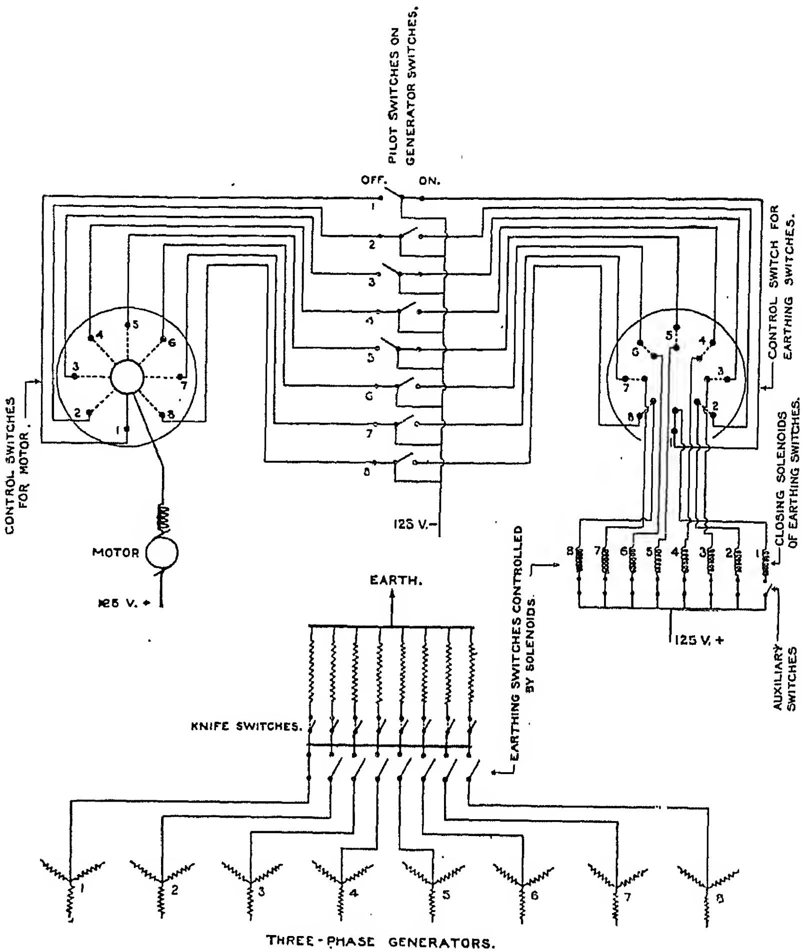
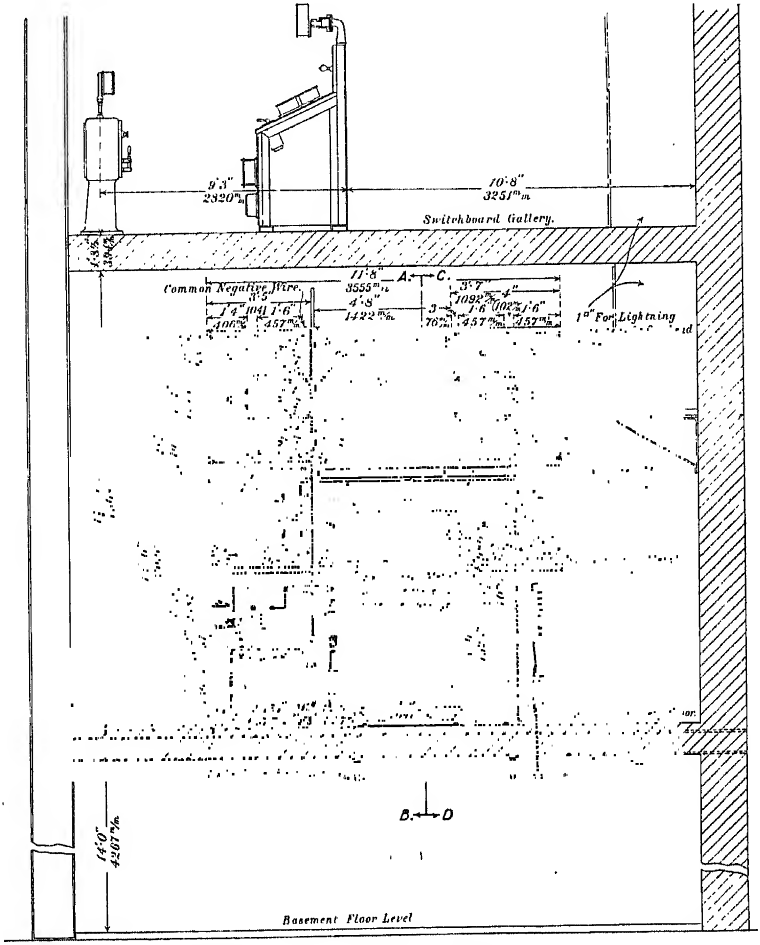


FIG. 136.

Governor Control from Switchboard.—There is also a governor control gear with a small reversible 3-phase motor worked by a simple reversing switch fixed on the control desk.

Earthing of Generator Neutral Points.—An ingenious switch for the automatic earthing of the neutral points of the generator

star windings is shown in Fig. 136. This apparatus consists of two sets of circular switches operated by a small direct current



SECTION OF FEEDER PANEL
FIG. 137.

motor through worm gear. If any running generator which has its neutral point connected to earth is shut down, either accidentally or purposely, then the switch automatically moves forward until it has connected to earth the neutral point of

another generator in circuit. For a full description of this im- portant piece of apparatus the reader is referred to Mr. J. H Rider's paper on "The Electrical System of the London County Council Tramways" ("Journal, Institution of Electrical Engin-

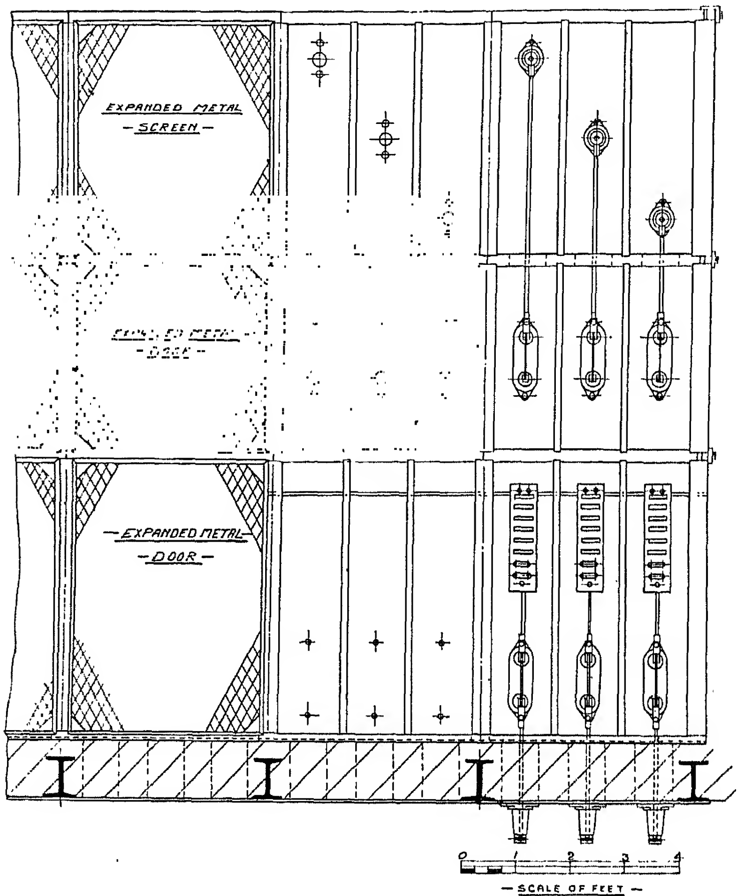


FIG. 138.

eers," vol. 43, 1909). It is well known that if the neutra points of several generators working in parallel are connected t earth, heavy local interchanges of current of the third harmoni occur between the various generators through the medium o the earthing connections. For this and for other reasons it i

important that only one generator should have its neutral point earthed.

Plates Nos. X. and XII. show the auxiliary low-tension switchboards for the motor, lighting, and other circuits in the power house.

Bahia Blanca H.T. Remote-controlled Switchboard.—Fig. 137 shows a section through the operating gallery and cubicle gallery in the Bahia Blanca power house and Figs. 138 and 139 front and back views respectively of the cubicles. Plate No. IX. is a diagram of connections, and Fig. 133 a photograph of the operating desk.

The normal pressure on the switchboard is 6600 volts between phases, and 3850 volts to earth. Some of the practical features of the switchgear will be of interest to the designer.

Duplicate H.T. Bus Bars.—In the first place, the main bus bars are duplicated, and each generator is connected through its series instrument transformer and oil-break switch (fitted with reverse current relay) to isolating links on each sectional bus bar. Each feeder is also connected to both sectional bus bars by isolating links, thence through an oil-break switch (with time limit overload relay) and series instrument transformer to the trifurcating box in which the three-core feeder terminates.

Pilot Lamp Indicators.—Each feeder or generator cubicle is represented on the operating desk by red and green pilot lamps indicating which particular isolating links are in circuit, so that the operator may see to which set of sectional bus bars each machine or feeder is connected.

Bus Bars.—There is an air space of 6 inches around each phase bus bar, and the current density of the bars worked out on the overload capacity of the generators at 0·8 power factor does not exceed 1000 amperes per square inch.

Oil-immersed Switches.—The solenoid-operated oil-break switches are arranged so that each phase is separately contained within its own sheet-iron cell which is lined with hard wood. The break between contacts when the switch is in the "off" position is not less than 4 inches. Phosphor bronze pins and bushes are fixed at all working joints of the switch mechanism so as to provide against rust, and consequent retardation of the

quick action of the mechanism. The solenoids are operated from the 110 volt exciter circuit. No rubbing contact was

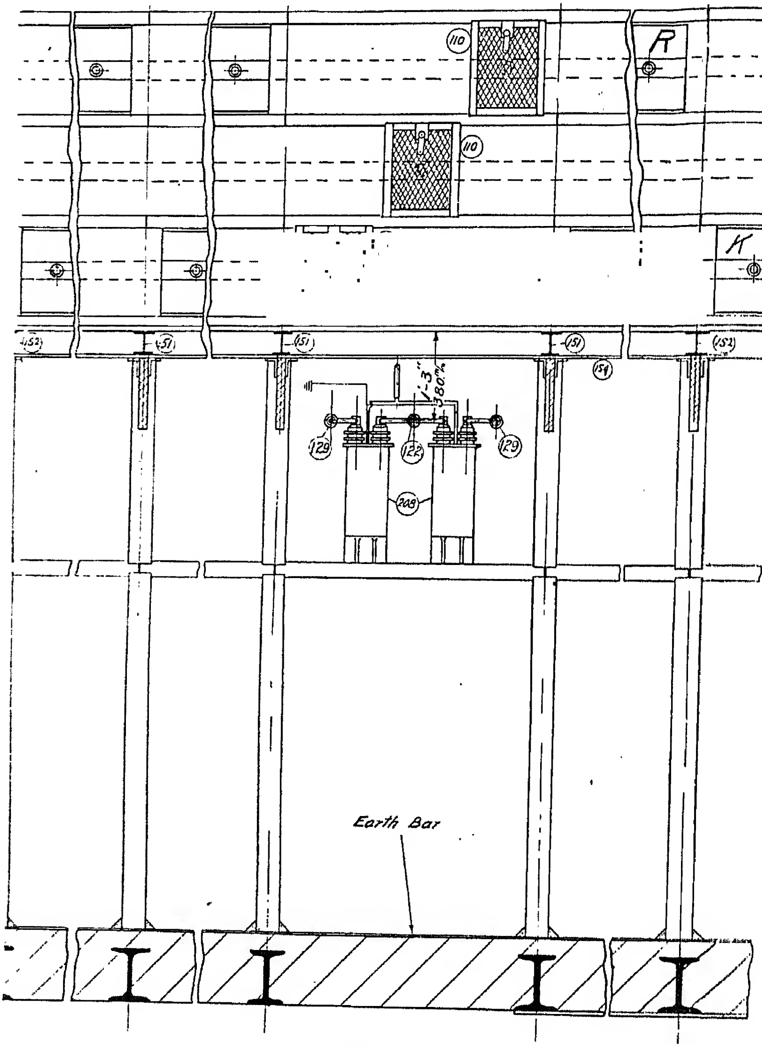


FIG. 139.

allowed a higher current density than 100 amperes per square inch, and the permissible maximum density for stationary current-carrying parts was 500 amperes per square inch.

The series instrument transformers and potential transformers are contained within cast-iron boxes filled with diatrine.

Other Details.—The connections between switches and bars within the cubicles are of special fireproof cable, and instrument leads and indicating lamp leads are of best quality rubber-covered stranded wires run in screwed steel conduits.

The oil-break switches, instrument transformers, bus bars, etc., are contained in separate cells of moulded stone and protected in front by Bostwick gates fitted with Yale locks.

The above-described switchboard represents a simple lay-out, and yet contains all the essentials for complete safety of control and ease of working. Owing to the employment of duplicate sets of bus bars, there is additional security against a shut down.

The designer should always take ease of working into consideration, and he is the more likely to do so if he has himself had experience in running a large power house. In emergencies the simple board has great advantages.

Buenos Ayres H.T. Switchgear.—The following is a brief description of the 13,000-volt switchgear at the Dock Sud Power House of Campanhia Allemanna Transatlantica, at Buenos Ayres. The switchgear is situated in a very spacious annexe to the engine-room, as shown in the sectional view in Fig. 30. Each generator, as well as each feeder, has a separate and independent control panel containing the usual pilot switch for the remote-controlled motor-operated oil-break switch situated in an isolated cubicle below, as well as the necessary instruments, synchronizing gear, and excitation control instruments. There is also a master control desk from which the operator can control the independent panels and their machines and feeders. There is an abundance of room and to spare, and the Author's criticism is that while adopting properly the independent panel system for such large units and so high a pressure (13,000 volts), there is an apparent want of system about the grouping of the switchgear, which is very much scattered. This is to some extent compensated for by the master control panel. The switchboard annexe and switchgear distribution must, however, have entailed unnecessary expense without corresponding safety of the arrangement.

Harbour Power House, Belfast: E.H.T. Switchgear.—The general scheme of the extra high-pressure switchgear for the Harbour Power Station, Belfast, is shown in diagram in Fig. 140.

The switchgear is divided into sections, and each section provides for one 12,500 K.W. (6600 volts) turbo-alternator (or its equivalent), and six feeder circuits.

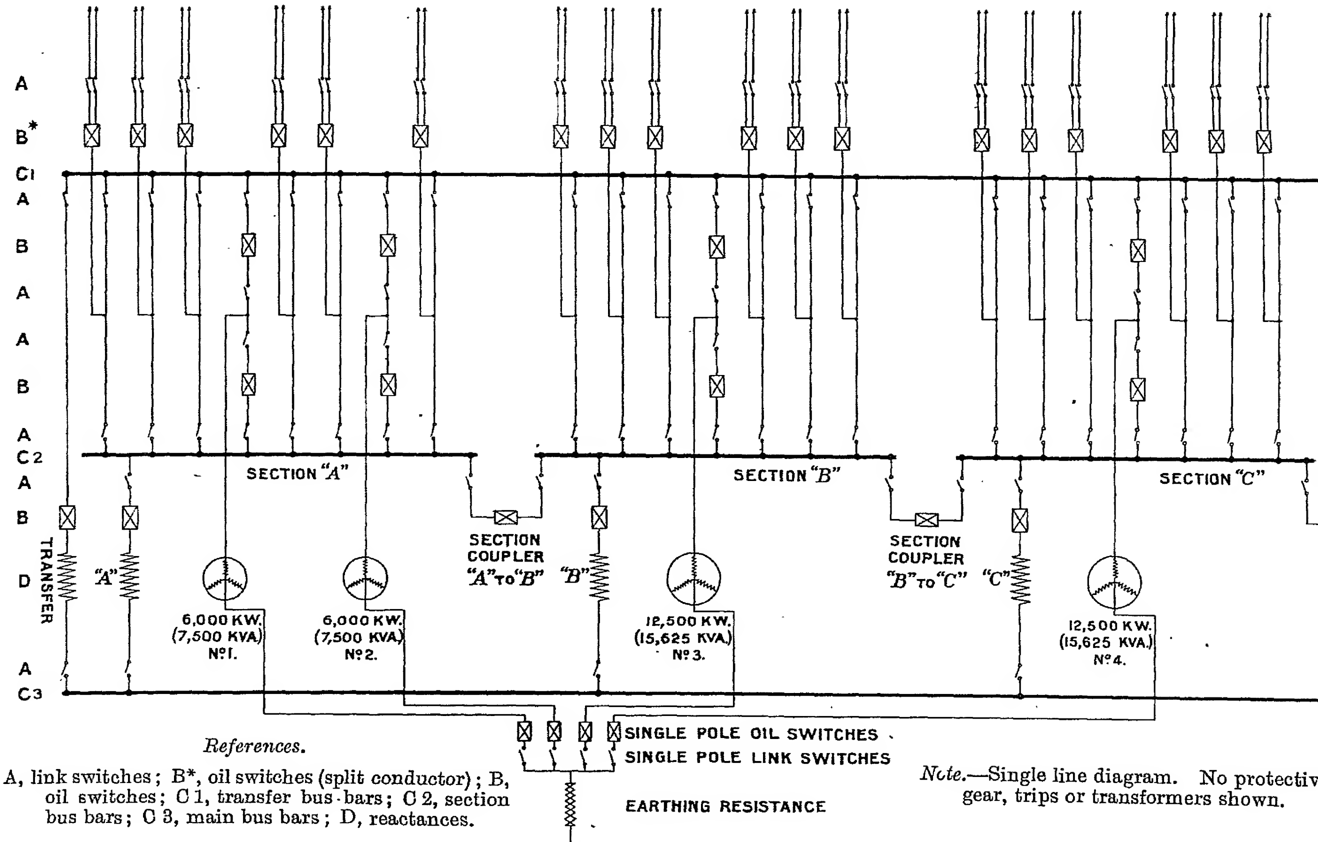
There are three distinct sets of extra high-pressure bus bars. The first set comprises "section" bus bars, or those peculiar to the sections into which the switchgear is divided. The second set comprises "transfer" bus bars, to which the alternator and feeders of any particular section may be transferred when desired. The third set comprises "main" or "tie" bus bars, which are connected to the bus bars of the individual sections, and to the "transfer" bus bars through reactances.

The bus bars of the adjacent sections may be connected together by means of "coupler" switches, and, in this manner, the series of section bus bars may be made into one continuous bus bar, or may be grouped together. Under ordinary working conditions, however, the bus bars of each section are kept distinct and separate.

If the alternator belonging to any section be out of service, that section is fed from the "main" or "tie" bus bars through its reactance. The main bus bars are fed from the section bus bars of the running alternators through the other reactances in parallel. The reactances are so proportioned that they will carry the full load of any one section with a pressure drop of not more than 5 per cent.

Should a short circuit occur on any feeder, with the alternator belonging to that section at work, only that one alternator would be under short-circuit conditions, because the remainder of the machines could only supply current to the fault through the various reactances, via the main bus bars.

Should the short circuit occur on the feeder of a section, the alternator belonging to which was not working, none of the running machines would be under short-circuit conditions, as the faulty section would be fed through its own reactance from the main bus bars, and then through the other reactances in parallel.



References.

A, link switches; B*, oil switches (split conductor); B, oil switches; C 1, transfer bus-bars; C 2, section bus bars; C 3, main bus bars; D, reactances.

Note.—Single line diagram. No protective gear, trips or transformers shown.

FIG. 140.—Belfast switchgear.

The transfer bus bars act entirely as section bus bars, and are normally kept out of action. They are intended to be used solely for the purpose of taking over the load from any one set of section bus bars when it is necessary to examine or clean the latter. They are not intended to be used to connect various sets of section bus bars together.

It will be noticed that two main oil switches are provided for each alternator, but only one oil-switch for each feeder. The failure of an individual feeder switch is not nearly such a serious matter as the failure of an alternator switch. It is seldom that a feeder switch is opened, whereas an alternator switch may be used several times a day. The oil switches on the feeder circuits are arranged for "split-conductor" protection.

A common resistance is used for connecting the neutral point of any one running machine to earth. The opening coil of the earthing switch of each alternator is connected in parallel with the opening coil of the main oil-switch which connects that machine to the section bus bars. Should, therefore, the earthed machine be disconnected from the bus bars, the earthing switch opens automatically at the same time.

The closing coils of the various earthing switches are so connected with the pilot switches of their respective alternator switches, that no earthing switch can be closed until its machine switch is first closed. It is thus not possible to "earth" a dead machine or to leave a dead machine earthed. A red pilot lamp is fixed above the control panel of each alternator, which is automatically lit when the earthing switch is closed. The attendant has therefore a constant indication as to which machine is earthed, and it is his duty, when switching off the earthed machine, at once to close the earthing switch of one of the other running machines.

Typical Specification for H.T. Switchgear.—As a typical specification for 3-phase high-tension switchgear, the Author will now indicate some of the salient features he has adopted in his own practice.

Typical Operating Board.—Generator panel containing—

(*a*) Operating switch to control the solenoids of the oil-break switch.

(*b*) Synchronizing plug and receptacles.

(*c*) Indicating watt meter with transformers.

(*d*) Ammeter in one phase only, to read to 50 per cent. in excess of generator rated output.

(*e*) Three-phase integrating watt-hour meter.

(*f*) Power-factor indicator.

(*g*) Reverse current relay, operating when 15 per cent. of the rated current is passing in a reverse direction.

Typical Feeder Panel.—Feeder panel containing—

(*a*) Operating switch to control the solenoid circuits to close or trip the oil-break switch.

(*b*) Three-phase integrating watt-hour meter.

(*c*) Overload time limit relay with a range of adjustment from, say 100 amperes to say, 250 amperes, and a time limit adjustment of from 5 to 30 seconds.

Typical Bus Bar Panel.—Disconnecting (or interconnecting) bus bar panel containing—

(*a*) Switch controlling the solenoid circuits to close or trip the interconnecting oil-break switch.

(*b*) Synchronizing plug and receptacles.

(*c*) Voltmeter with two potential transformers (one for each set of bus bars) and a throw-over switch.

Typical Synchronizing Panel.—Synchronizing panel or swing bracket containing—

(*a*) Bus bar voltmeter with illuminated disc and 18-inch scale calibrated say from 5500 to 8000 volts.

(*b*) Synchroscope with red and green signal lamps.

(*c*) Vibrating reed frequency indicator.

Typical Exciter Pillar.—Excitation control pillars each containing—

(*a*) Circular dial moving coil ammeter for the generator field circuit.

(*b*) Generator field rheostat hand wheel.

(*c*) Generator field-breaking double-pole switch with non-inductive resistance.

(*d*) Reversing control switch for governor motor.

Typical Transformer Panel.—Transformer panels (for supply of auxiliary power within the station) each containing—

(*a*) An operating handle to control the oil-break switch.

(*b*) Ammeter complete with instrument series transformer.

In addition to the above schedule of H.T. Switchgear there are usually the L.T. excitation and L.T. alternating boards. These may be summarized as under—

Typical Exciter Control Panel.—Separate exciter panels each containing—

(*a*) Ammeter.

(*b*) Integrating watt-hour meter.

(*c*) Receptacles for paralleling voltmeter.

(*d*) Double-pole quick-break knife switch.

(*e*) Hand wheel for exciter field rheostat (the rheostat being fixed immediately behind the panel).

A large voltmeter with illuminated dial should be fixed above the board.

Typical Lighting Panel.—Power house lighting panels each containing—

(*a*) Ammeter.

(*b*) Main double-pole quick double-break knife switch to carry the whole current required.

(*c*) A double-pole quick-action double-break knife switch to carry the current in each separate circuit (one to each branch).

(*d*) Two single-pole porcelain-handle switch type fuses for each branch circuit.

Typical Low Tension A.C. Board.—The following auxiliary panels are generally required—

1. Power house transformer panels each containing—

(*a*) Hand operated oil-break switch with automatic quick "make" and "break".

(*b*) Indicating watt meter with instrument transformers.

(*c*) Integrating watt-hour meter with instrument transformers.

2. Motor control panels for the various motors or groups of motors used throughout the power house for condensers, fans, travelling cranes, etc., each containing—

(*a*) Hand operated oil-immersed switch fitted with automatic A.C. trip coil;

(*b*) Ammeter;

or, (*a*) Triple-pole knife switch;

(*b*) Three porcelain-handle switch type fuses;

(*c*) Ammeter;

according to the size of the motors or groups of motors to be controlled.

Requirements of a Well-designed Board.—The designer, when considering the lay-out of a switchboard, would do well to give special attention to the following points:—

1. Separation of the mechanism either in cubicles or on different galleries; so that in the event of a burn-out of one oil-break switch, any resulting explosion or flame may not affect the neighbouring cells, or by access to the main bus bars, continue the "arc" to them. The same consideration applies to instrument transformers. It must be remembered that a very important railway power house was shut down and the whole traffic stopped through the burning out of an instrument series transformer and the communication of the arc to the apparatus above it.

2. Safe accessibility to all the parts for cleaning and inspection. This entails a design which must necessarily have duplicate or sectional bus bars and such a system of isolating links that the section to be inspected may be positively disconnected. Insulators must be kept clean, and thus a periodical system of inspection and cleaning must be insisted upon.

3. Facilities for removing the cases of oil-break switches, so that the contacts and insulators may be periodically examined and the oil periodically changed. This last matter is one of very great importance.

4. The careful selection for the cubicles either of moulded stone which must be so made up as to be practically non-absorbent of water; or of hard, well-burnt, first-quality glazed bricks.

5. Liberal space around the cubicles and switch gear generally, as well as a thoroughly good light. When laying out H.T. gear, consideration of space ought not to come in, and a liberal allowance must always be made especially having regard to the enormous, if momentary, energy behind any sudden dislocation.

There are other types of operating boards, such as small dummy diagram boards, having the main connections picked

out in relief on the face so that the operator sees exactly from this model what switches are "on" and which are "off". An illuminated dial may be used, which by a system of lamps will also show the same thing pictorially. The Author thinks, however, these are quite unnecessary complications, involving a good deal of small low-tension leads and making the switch gear unnecessarily complex.

In the Author's opinion, the best practice in the case of a large and important power house is to arrange the H.T. switchgear in a separate switch house built as an annexe to the main building. Such an arrangement was designed for the large power house projected for the supply of the County of London, and has been adopted at the Dunston power house of the Newcastle-on-Tyne Electric Supply Co., and elsewhere. So much depends on the safe working and control of the main switchgear, that this will be found a wise provision to make.

Isolated Pedestal H.T. Switchgear.—For very large machines the pedestal and self-contained type of gear has a good deal to commend it. The energy carried by each switch is so great that in the event of a fault occurring in the switch, isolation may prove to be very necessary.

In this ironclad type of switchgear, the bus bars are completely encased and thus made dust and moisture proof.

Fig. 141 shows an elevation of a remote control gear of this type as made for pressures up to 12,000 volts, a front view of the operating side being shown in Fig. 142. The chief claims for this type of switchgear are—

(*a*) Accidental contact with live metal is impossible.

(*b*) Dust, moisture, and vermin proof.

(*c*) Fire and short circuit risks minimized.

(*d*) Minimum amount of cleaning.

(*e*) Insulation able to withstand any excessive pressure likely to arise on the system.

(*f*) The parts requiring cleaning or inspection are readily and completely detached from the bars, so that the inspection may be carried out in absolute safety.

(*g*) Switch mechanisms are so situated as to be under observation.

(*h*) Mechanical strength.

Fig. 134 shows a H.T. panel suitable for arrangement on a system of independent panels. Locking-off doors on the 3-phase connections, by which all live parts are protected when the switch is removed for inspection, are shown in the figure.

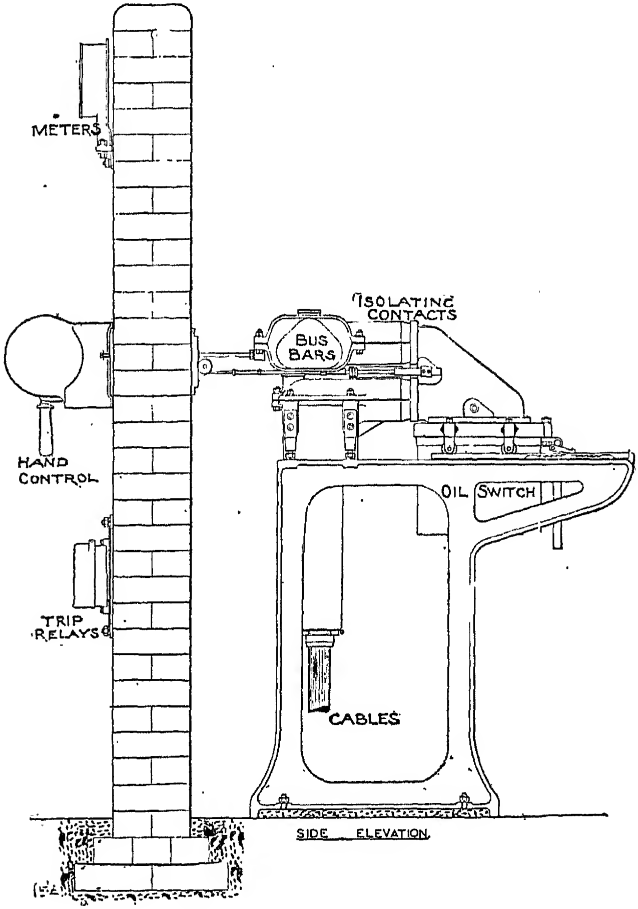


FIG. 141.

In some Continental power houses the oil switch, etc., is carried on a traveller. By drawing the latter out from its cubicle, the switch is positively disconnected and readily inspected and cleaned. For high-pressure and extra high-pressure

switchgear, however, a fixed arrangement is to be recommended as giving greater rigidity and less chance of broken insulators. Provided the design embodies the principles set out above, the fixed ironclad system has advantages over any "carrier" system.

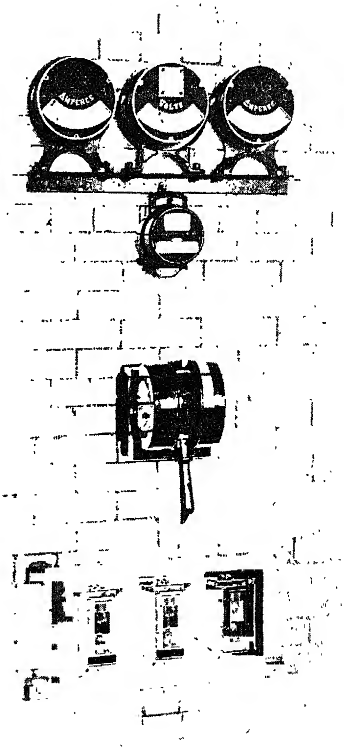


FIG. 142.

Switch and Transformer Oils.—Before leaving the subject of high-pressure switchgear, some mention of the oil to be used in switches and in transformer-cases may be made. This is a most important matter.

The oil chosen should be of a high dielectric strength with a flash point not less than 177° C., and free from water, sulphur

compounds, acids, or alkalies. A very minute amount of water present in the oil, such as may result from condensation inside empty steel drums, is sufficient to reduce the dielectric strength enormously and to constitute a serious danger, especially when the oil is used in oil-break switches. It is usual to specify that the oil shall have a dielectric strength sufficient to withstand, without breaking down, an alternating pressure of 14,000 volts measured between needle points $\frac{1}{8}$ of an inch apart; and that its viscosity at a temperature of 35° C. shall have a value of 7 minutes with Redwood's viscosimeter.

The oil should be tested periodically—in oil-break switches say once in every six months, and in main transformers say once every year. There is sometimes used on extra high-pressure systems a portable apparatus which pumps out the oil from the transformer casing and subjects it to a considerable heat from steam coils so that any moisture present is driven off, the oil then being returned to the casing.

Direct-Current Switchboards.—These main switchboards in power houses are more complex than alternating current boards. Direct-current power houses usually have to supply two independent systems, one for general supply, usually on the 3-wire system, and the other for traction. There is the further complication arising on the general supply section in the requisite balancing and middle-wire-earthing apparatus and also the usual auxiliary battery control panels.

Some designers have adopted one main switchboard common to both systems. The Author thinks this is a practice to be deprecated, as it involves much complication and crowding, especially at the backs of the panels, as well as a mixing up of bars at differing potentials. There is nothing to be gained except perhaps a small amount of space. It is far better to keep the traction board distinct from the general board.

L.T.D.C. 3-wire Supply Board.—The following description of a typical general supply direct-current board may be given.

Each panel usually accommodates the instruments and switches, etc., for one generator and for one or two feeders. There are two sets of bus bars, i.e. the main bus bars and an

auxiliary set, so that long distance feeders or a faulty section outside may be run on separate machines.

Each generator panel usually contains the following instruments :—

(*a*) Reverse current circuit breaker on one pole.

(*b*) Main quick-break knife switch on the other pole.

(*c*) Machine ammeter and shunt.

(*d*) Paralleling receptacles for voltmeter.

(*e*) Vertical straps for plugging the machine to either set of bus bars; or alternatively, a throw-over switch by which the machine can be connected to either set of bars. This latter arrangement is preferable as it is positively protective against plugging a machine on the wrong bars.

(*f*) The integrating watt-hour meters are usually fixed separately so as to prevent overcrowding on the main board. These may be conveniently fixed on the wall at the back of the board, within observation, but away from interference by unauthorized persons.

Each feeder panel usually contains the following instruments :—

(*a*) Main switch, on each pole, capable of carrying the maximum probable overload on the feeder.

(*b*) Ammeter and shunt, one on each pole (unless the system be a simple 2-wire system).

(*c*) Magnetic blow-out fuses, or what is preferable, overload time limit circuit breakers. These latter must be set well above normal or probable overload currents, as momentary short circuits outside may otherwise dislocate the supply.

(*d*) Vertical bus bars and plugs for connection to either of the duplicate horizontal bus bars.

A middle wire and balancing panel contains instruments for (*a*) earthing the middle wire, and (*b*) balancing purposes.

The earthing arrangements comprise—

(*a*) Ammeter with middle zero, so as to read the out-of-balance current on either side of the 3-wire system.

(*b*) Step switch for controlling the resistance through which the middle wire is connected to earth. The resistance is situated away from the board.

(*c*) Fusible cut-out, to disconnect the middle wire in the event of a heavy ground outside on either of the outer conductors, and to cut in the limiting resistance.

The balancing arrangements comprise—

(*a*) A double pole switch to control the balancing transformer motor.

(*b*) Field control switch for same.

(*c*) Double pole switches for each generator, one positive and one negative.

(*d*) Ammeter on each balancer.

In addition to the above the equipment requires—

(*a*) Complete set of pilot voltmeters, including large illuminated voltmeters with 18-inch dials one on each side of the middle wire.

(*b*) Multiple pilot switch to control the pilot leads on each feeder. The pilot leads are best brought to a supplementary assembly board away from the main board, with leads taken thence to the multiple switch on the main board.

If a battery is used then a supplementary panel will be required for its control. The arrangement will depend on the type of booster adopted, but generally the panel will contain—

(*a*) Main switch on each pole.

(*b*) Circuit breaker on each pole.

(*c*) Ammeter to read both charge and discharge.

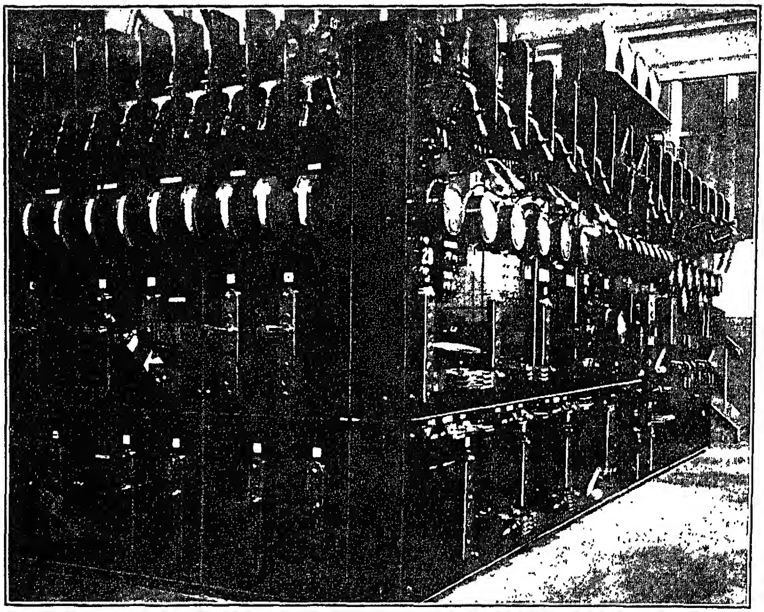
(*d*) Voltmeters.

(*e*) Booster switches, according to the type used.

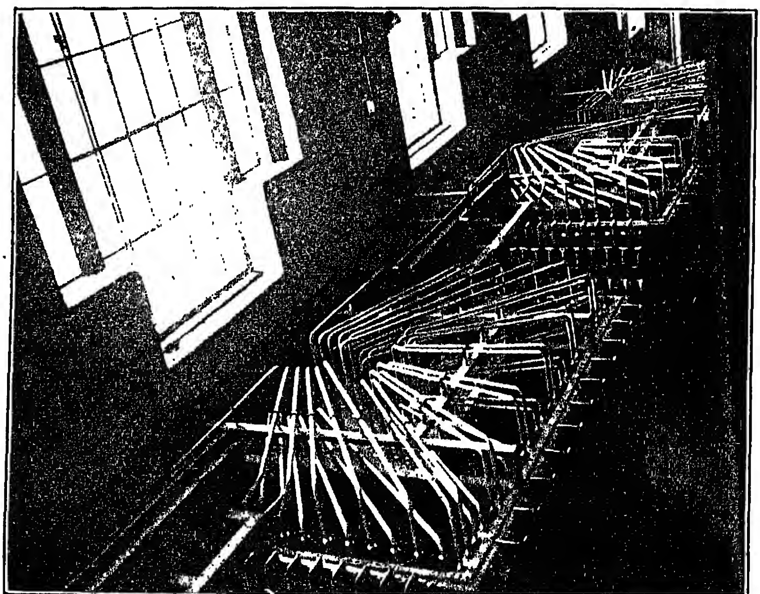
The battery input and output energy meters are usually fixed separately and away from the main board.

Fig. 143 shows the front views of the operating panels and the aluminium rod connections of the 3-wire low-tension switchboard designed by Mr. Bernard Jenkin, and erected at the Horseferry Road Station, Westminster. To get a maximum available number of operating panels the boards are arranged to form three sides of a rectangle, the generator panels being kept mainly on the front and the feeders on the two sides of each group.

The whole of the connections and the heavy bus bars are of aluminium, and run direct from the backs of the panels to



Elevation.



Plan

FIG. 143.

the end of a long tunnel, where they join the special end connections of the street cables. The board and the whole arrangement of connections is one of the neatest and best controlled the Author remembers to have seen. It is quite fireproof, the bare aluminium rods being supported by porcelain insulators in frames; and the poles are kept well apart. Practically the only danger is from the accidental earthing of one of the conductors, and this is well-nigh impossible owing to the well-designed arrangement of the latter.

Design of D.C. Switchgear.—The principal points to be observed in laying out direct-current switchgear are as follows:—

(*a*) The panels should be grouped so that the operator can control the feeders connected to the board, and more particularly the generators, without having to do a "sprint" each time some regulation has to be made.

(*b*) Plenty of space should be left both in front and behind the board. There should not be less than 4 feet 6 inches from the outermost conductor on the back of the board to the wall, or to the meter cases if the latter are fixed on the wall. Head room must also be considered, and conductors from the board to the wall should give a clear headway of not less than 6 feet 6 inches.

(*c*) The bus bars and straps should be so spaced as not only to give accessibility for cleaning and adequate cooling area, but also that connections may be tightened up without risk of short circuit or shock. Bus bars are sometimes taped, but in any case they must be kept several inches from the backs of the panels so that they have a clear air space from the connecting straps on the panels and from the steel framework.

(*d*) Small instrument leads on the back of the panels should be reduced to a minimum in number, and neatly and symmetrically run on porcelain insulators. All connections should be at the backs of the board. Fireproof leads should be used. Connections through the panels should be bushed.

(*e*) Feeder cables should terminate away from the board and be continued by bare copper rods or straps to the bars, the idea being to keep all possible inflammable material away from the board.

(*f*) On the operating side, switches should be so arranged as not to stand out when in an "off" position and block the passage way. Instruments should be arranged at a level where they can be read by the operator without either breaking his back or ricking his neck! Circuit breakers or fusible cut-outs should be fixed at the tops of the panels, so as not to "blow" in an operator's face; if situated lower on the panel, the vaporized metal might cause an arc in the connections above them. Resistances for field rheostats, etc., should be fixed well away from the panels, and in most cases separate excitation pillars are preferable, so as not to congest the main board. On the whole, either white or grey marble slabs, with instrument cases finished dull black, are best, as they have a good appearance, and also minimize the amount of "powder and polishing paste". Marble, if free from metallic veins, is better than slate, being less absorbent; though with direct current boards dust figures may form around the negative connections if the board be not kept scrupulously clean, and if any oil vapour is present the marble may be stained.

The heavy bus bars should be carried on brackets from the steel framework, with insulators, so as not to throw strains on the marble or slate.

Slate must, of course, be enamelled both back and front, and has a sombre appearance especially if the instrument cases are finished dull black; on the other hand, lacquered brass or even aluminium cases require a good deal of cleaning, which costs money.

For the working current densities of metals on direct-current boards, see p. 379.

An extract from the British Home Office Regulations (1909) is given in an Appendix at the end of this book, and this should be referred to by the designer. The Regulations embody the considered necessities for good and safe practice and are the result of a lengthy inquiry at which the leading experts, contractors, and manufacturers were represented.

L.T.A.C. 4-wire Supply Board.—For 3-phase 4-wire distribution, the switchboard illustrated in Fig. 144 may be taken as a type.

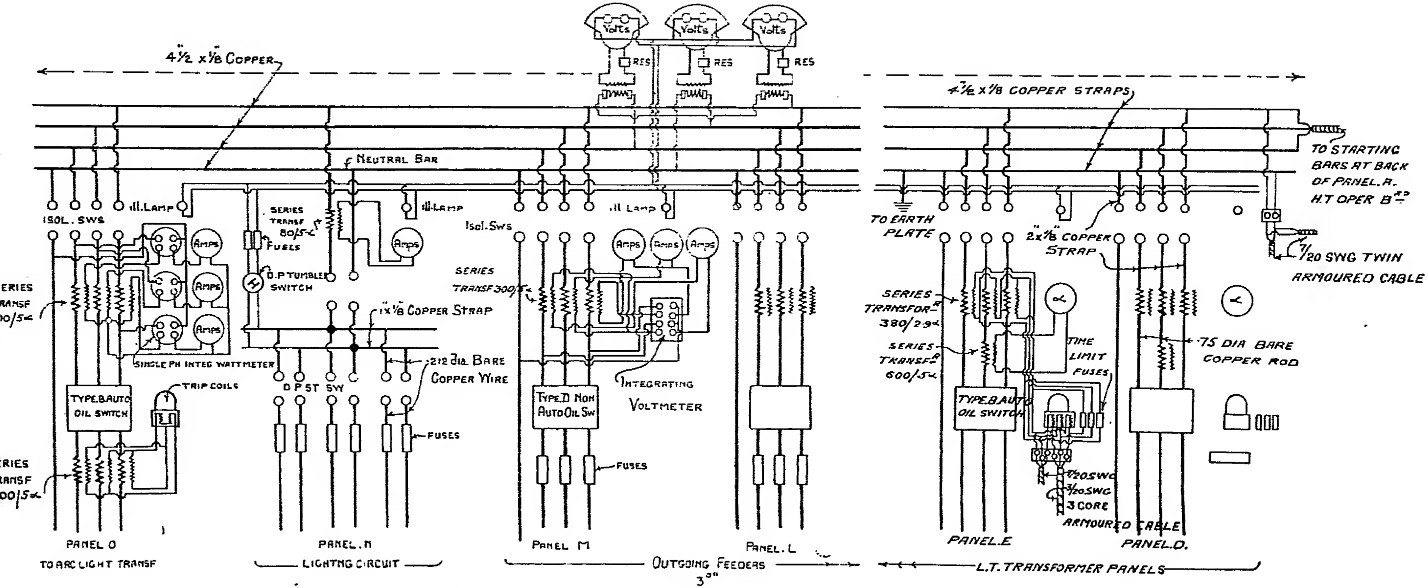


FIG. 144.—Diagram of connections of L.T.A.C. board.

The arrangement comprises—

1. Six transformer control panels for supplying the general network.

2. Twelve outgoing feeder panels.

3. Street arc lighting panels to control the constant current transformers.

4. Panels for the power house auxiliary motors and lighting.

The panels are mounted in a mild steel framework bent to shape, riveted up and suitably stayed, the whole being finished dull black including the bolts and the instrument cases. The panels are of white marble 2 inches thick, straight bevelled at all edges, and the bolts holding the slabs to the framework are bushed and capped.

Each transformer panel contains—

(*a*) A handle to operate the levers of the oil-immersed switch controlling the transformer secondaries.

(*b*) Three ammeters, one on each phase, with current transformers.

(*c*) One voltmeter on one phase, with potential transformer.

(*d*) Integrating watt-hour meter with current and potential transformers.

Each feeder panel contains—

(*a*) One oil-break switch operating handle, as above.

(*b*) Three ammeters, one on each phase, with series transformers.

(*c*) One indicating watt meter, with potential and current transformers.

Each street arc lighting panel contains—

(*a*) An automatic oil-break switch, mounted on the back of the panel, with lever handle in front, complete with trip coil and series transformers.

(*b*) Three long-scale ammeters, one on each phase, with instrument transformers.

(*c*) Three single-phase watt-hour meters (one for each phase), complete with instrument transformers.

L.T.D.C. Traction Board.—Fig. 145 shows a typical traction board in use on the London County Council tramways. This has some special details not common to trolley systems, as the

conduit conductors have to be reversed in polarity from time to time. The track feeder panels have double-pole change-over switches, so that the feeder controlled may be reversed in polar-

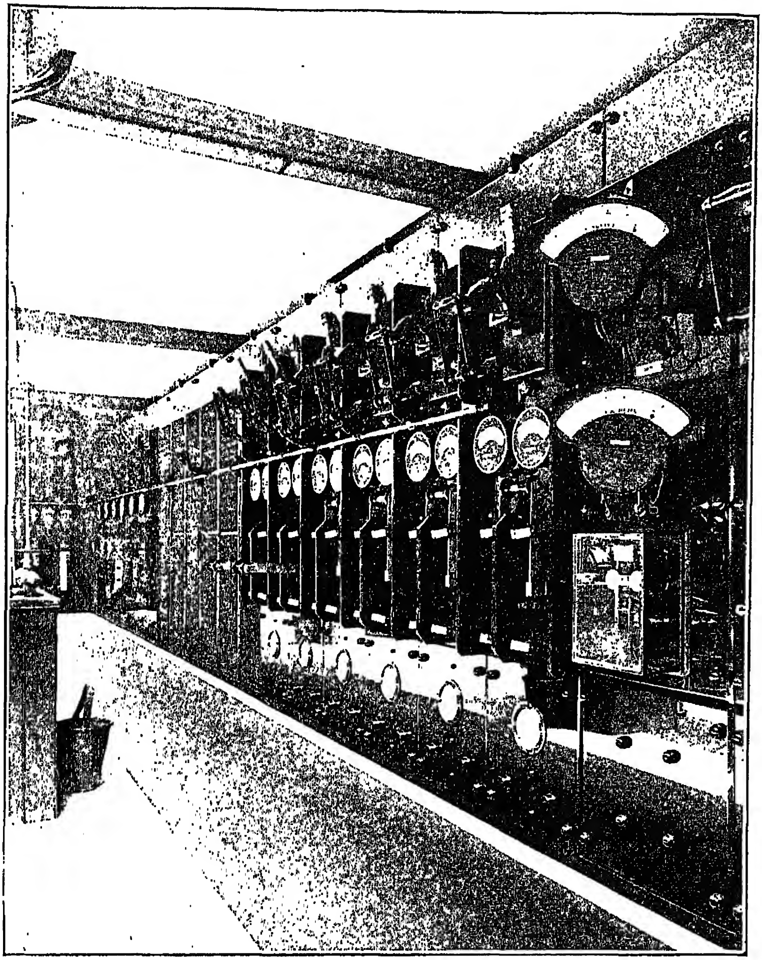


FIG. 145.—L.T.D.C. traction board.

ity without in any way interfering with the bus bar polarity. The change-over switch has auxiliary contacts on each pole both at the top and bottom positions. These auxiliary contacts are

insulated from the main contacts. When the switch blades are pulled out of the main contacts into the auxiliary contacts, the track feeders are connected to the main bus bars through a fixed metallic resistance of 5 ohms and a special testing panel. By these means it is possible to see whether a fault in the feeders or conductor section is a bad one or not. The track circuit breakers are of the plain overload type without time limit. The generator circuit breakers are of the reverse current type; and in this case, as the board is supplied by motor generators, the circuit breakers are cut out by the use of a separate starting panel when a motor generator is being run up.

Traction Board with Rotaries.—Plate No. XIV. shows a typical direct-current traction board for the control of four rotary converters and five track feeders.

Each rotary panel contains the following instruments :—

(*a*) Change-over switch and pole indicator.

(*b*) Double pole quick-break knife switch, to take maximum overload current.

(*c*) Ammeter with shunt.

(*d*) Integrating watt-hour meter.

(*e*) Equalizing knife blade switch.

(*f*) Receptacles for Kelvin paralleling voltmeter.

(*g*) Single pole circuit breaker, with reverse current trip coils, and copper rod choking coil.

(*h*) Adjustable reverse current relay with shunt.

Each track circuit feeder panel contains—

(*a*) Single pole plain overload circuit breaker and copper rod choking coil.

(*b*) Single pole quick double-break knife switch, to take maximum feeder current.

(*c*) Ammeter and shunt.

(*d*) Lightning arrester complete with isolating switch.

The leakage testing panel is fitted with—

(*a*) Double scale circular dial ammeter.

(*b*) Three recording voltmeters, with scale from 0-10 volts.

(*c*) Recording voltmeter for line voltage.

(*d*) Four five-point voltmeter switches for pilot wires.

(*e*) Two small knife switches for leakage ammeters.

Practical Notes on Switchboard Materials.—The following practical points may be considered when designing or selecting switchgear.

Copper bus bars should be designed to work at a current density of not more than 1000 amperes per square inch. The bus bars, however, may be either of copper or of aluminium, and in the latter case the current density should not exceed 800 amperes per square inch. Large bus bars are usually built up of metal strips with separators to enable a maximum radiating and cooling surface to be obtained.

The current density in the rubbing contacts of circuit breakers, etc., should not exceed 100 amperes per square inch at rated load, and of switches 60 amperes per square inch.

Fixed switch parts, straps, links, etc., if of copper should not work at a higher current density than 800 amperes per square inch; and 500 amperes per square inch if of aluminium. Similarly, the current density in brass should not exceed 250 amperes, in gun-metal 200 amperes, and in phosphor bronze 300 amperes per square inch.

Resistance grids should not have a higher temperature rise than 66° C. (151° Fahr.) at their rated current after one minute.

H.T. current transformers should be subjected to a pressure test between primary and secondary of at least $2\frac{1}{2}$ times the working pressure for 5 minutes, as well as a heat run (before the compound is run in) for say 3 hours at rated load, 2 hours at 25 per cent. overload, and 15 minutes at 50 per cent. overload. At the end of this run the rise of temperature between any accessible part of the coils and the surrounding air should not exceed 40° C. (104° Fahr.).

Similarly with potential transformers, the H.T. windings should be tested for 5 minutes with a pressure of not less than $2\frac{1}{2}$ times the working pressure (the secondary being earthed during the test); and the low-tension windings tested at a pressure of 2000 volts for a like time. They should also be subjected to a heat run for 6 hours with a temperature limit as in the case of the current transformer above.

Instruments should be supplied with a margin of error not to exceed the following:—

(*a*) Voltmeters, ammeters, watt meters, and integrating watt-hour meters.

25 per cent. overload . .	2	per cent. error
Rated load	1	,, ,,
$\frac{1}{4}$ to $\frac{3}{4}$ load	1·5	,, ,,
Below $\frac{1}{4}$ load	2·5	,, ,,

(*b*) Overload time limit relays.

Time error, 3 per cent.; current error, 10 per cent.

(*c*) Reverse current relays.

15 per cent. of full load at any pressure between normal voltage and one half normal voltage.

Space required for Switchboards.—If a high-pressure board is necessary, then galleries have to be provided as shown in a previous illustration (Fig. 137).

If the outgoing feeders consist of cables, then the best sequence of galleries will be (1) basement gallery for cable race, (2) cubicle and switch gallery at engine-room level, (3) operating gallery. The cables from the generators are then taken through ducts directly into the cable race to the trifurcating boxes fixed in an accessible position. The rubber tails are thence taken on suitable insulator supports to the terminals of the isolating links controlling the oil-break switch on the floor above (engine-room level), the circuits then passing through the other apparatus to the bus bars.

Similarly, the feeders enter into and run through the cable race to trifurcating boxes, and thence to their control gear as in the case of the generators.

This enables a minimum length of expensive cable and also a minimum length of tails to be employed.

If the outgoing feeders are run overhead then the above arrangement may be reversed. The operating gallery may either be at engine-room level or in a more commanding position above, and the switch gallery can be made the floor above the operating gallery, as shown in Fig. 132.

When cables are run vertically up the walls of the building, glazed brick chases, in which the cables can be neatly run and cleated, can be built into the face of the wall at the time of construction.

Due regard must be given to the good lighting of these galleries both by day and by night, and also to good ventilation.

The clear distance between floors should not be less than 8 feet. The gallery at the front and back of the cubicles should not be less than 3 feet 6 inches in width in each case.

Distributed Weights on Galleries.—The usual concentrated weight of the stone cubicles, oil-break switches, etc., is 3 cwts. per square foot (excluding the weight of the concrete floor). The filling between the steel joists forming the floor is of concrete, and cutting away should be avoided by inserting boxes in the concrete at the necessary points so as to have holes through the floor for the cables. The cubicles must of course be so arranged with regard to the rolled steel joists as to enable the cable access holes to be symmetrically spaced out and not to foul a joist.

Direct-current boards require of course only one gallery, or they can be placed on a dais in the engine-room. The clear space in front of a board (measured from any projecting connections) should not be less than 3 feet, and behind 4 feet 6 inches. The clear head room behind the board between the floor and any connections running overhead should not be less than 6 feet 6 inches. Very careful attention to these dimensions was given by representative inquiries during the framing of the Factory Regulations for Great Britain, and the above-mentioned figures were the minima then fixed. (See the Appendix, already referred to, which contains an extract from these Regulations.) Good light must be allowed both in front and behind the board.

The floor should be laid as to prevent any attendant from making "earth" when working on the connections at the back of the panels. Resistances can be fixed below the floor level or on the wall behind the board, and the clearways given above must of course be independent of such fixtures.

Important Notes for Designers.—For very large power houses, as has been urged before, a switch annexe separate from the main building should be constructed, allowing ample space for the gear and the cables.

In laying out a power house the designer should also lay out the general switchgear. In many cases it is clear that while

adequate consideration has been given to the plant and piping, flues, etc., too little attention has been paid to the switch room. When a rough space only has been allowed, it may afterwards be found that the gear is cramped and that the space provided for inspection and cleaning, or for repairs, is inadequate.

CHAPTER XI

LARGE AND SMALL POWER HOUSES AND SUBSTATIONS

THE Author has dealt in the preceding chapters with the various civil engineering, mechanical, and electrical problems constituting the principal elements of power house design. Attention has been drawn to particular features distinguishing a good design from one of an indifferent character, and emphasis placed upon the importance of simplicity.

It is apparent that many considerations have to be taken into account in evolving a design that will prove fully satisfactory for the purpose in view, and that much depends upon the skill and judgment displayed by the designer in co-ordinating the practical elements of the problem submitted to him. From this standpoint, it will be appropriate, in the present chapter, to give a brief description of the salient features of some typical power houses and of typical substations.

Although engineering questions constitute one of the principal items in the work of a designer, there are other relevant factors of a less tangible character to which he must give careful attention if the financial success of a scheme is to be assured. For example, he may be called upon to demonstrate that a new power house should be erected in a district already partly served by other stations in preference to extending one of the existing stations; or to show that the needs of a particular factory can be more economically met by installing suitable power house plant at the factory than by taking a supply in bulk from an existing source. In countries where the use of electricity is rapidly increasing, as in Great Britain, the importance of a sound conclusion in regard to the whole of the possibilities may add largely to the responsibilities of an engineer when advising upon a particular scheme.

Owing to the variety of the local factors that may have to be considered in connection with the design of a proposed power house, it is not possible within the limits of the present chapter to give more than a short summary of some of the more important. The Author therefore proposes to confine his observations to matters such as the modern tendency in power house design; the possibilities attaching to combinations of high and low load factor stations for the supply of electricity over wide areas; the bearing of the load curves of a power house upon the choice of the number and sizes of the units of power plant; the relative economy of small power houses as compared with a bulk supply; and the capital and running costs of stations of various sizes. The important question of fuel economy also demands consideration, and notes are given upon the thermal aspects of power generation from coal and upon proposals aiming at the maximum utilization of fuel resources, such as the application of by-product recovery processes to power generation on a large scale, and the utilization of waste heat.

Modern Tendencies.—The modern tendency is towards concentration of generating plant in large stations situated, wherever possible, in positions affording an abundant supply of circulating water and ample facilities and room for handling and storing coal.

It is becoming more and more necessary to consider power houses as centres of supply not only for industrial, factory, and domestic needs but also for railway and other traction and for agricultural purposes; in fact, as essential to human progress in almost every phase of development. This progress must lead to the establishment of large generating stations, and it has already been pointed out that larger units of power plant are cheaper per K.W. than smaller units, require smaller buildings per K.W. installed, and generally speaking consume less steam per K.W.H. generated. Nevertheless, in laying out a system regard must be had to the cost of transmission which will certainly put an economic limit to the radius of supply from any coal-fired power house. In addition, the size of the power house itself will be limited by the increasing magnitude of the requirements for condensing water and fuel. The intense

development of explosives and other military weapons provide reasons of a different category why too great a concentration of plant, upon which a whole province may depend for its means of livelihood, for domestic necessities and for transport, is to be deprecated.

Generally speaking, it will prove more economical in the case of a scheme involving, say, 200,000 K.W. of plant, to build two separate stations some miles apart each of 100,000 K.W., than to concentrate the whole of the plant on one site. While this is usually so even for a new and electrically undeveloped district, it is especially the case in districts where there are existing local stations capable of dealing with a proportion of the load. This point is dealt with in the following paragraphs.

Combinations of High and Low Load Factor Stations.—In Great Britain the output of electrical energy doubled during the European War, and an accelerated rate of growth has to be reckoned with in the future. Owing to the greater cost of buildings and plant and also the higher price of coal, a reform of the methods of generation is rendered even more necessary than would have been the case prior to the war. In any case it is now recognized that, although there is an economical limit to the distance over which electricity may be transmitted from a coal-fired station, electricity must be generated in large power stations employing large units of plant, high steam pressures, complete coal and ash handling appliances, and in situations where there is an abundant supply of circulating water at low temperatures thus ensuring a high vacuum: the whole resulting in a high thermal efficiency.

A comprehensive system of supply from two or three well-situated large stations would now be adopted to serve any wide industrial district in which there were no existing stations. Where, however, there are such existing stations then subject perhaps to the improvement of selected local stations, all further supply up to a limit would undoubtedly be given from a well-placed capital station. This latter station would be arranged to work at a high load factor and the smaller local stations at comparatively low *station* load factors, though the system as a whole would be worked in such a way that even in the smaller stations

the plant would be operated at as high *plant* load factors as the load curve allowed.

Upon analysis of the integrated load curve for a typical industrial district, it will be found that it can be split up into two components, one representing an average yearly load factor of from 70 to 80 per cent. and the other an average yearly load factor of from 25 to 30 per cent. A typical weekly load curve covering a large industrial district and integrated from actual curves from public supply undertakings, collieries, traction systems, etc., is given in Fig. 146. The maximum load attained was about 180,000 K.W. and the weekly load factor of the lower portion of the curve (90,000 K.W.) is 87 per cent.; for the remaining maximum demand of 90,000 K.W., the weekly load factor is 31 per cent.

This characteristic has an important bearing upon the economics of general supply and for the following reasons. It is not as a rule worth while to transmit low load factor units from a considerable distance, and it is only in rare cases that a good site of the area necessary for a large station, with good rail facilities and an abundant natural supply of circulating water, will be found near the point of densest load. More often such a station would have to be built at some distance from the centre of densest load. By splitting up the maximum load on the system into halves as above indicated, it is obvious that the transmission system is greatly reduced in cost (it is in fact reduced to the minimum possible). At the same time the most economical though distant station is employed in generating the greatest output at a high load factor and therefore at the lowest fuel consumption per unit. Although consuming the largest proportion of the total coal required, the station will be situated where the coal can be more readily delivered (probably both by rail and by water) and stored, and whence the ashes can be most readily removed.

The local stations nearer the densest load will consume only a minimum proportion of the total coal requirements, though burning a larger amount per unit generated by them at the lower load factor. This relieves transport, improves the local amenities by reducing smoke and dust and involves many other

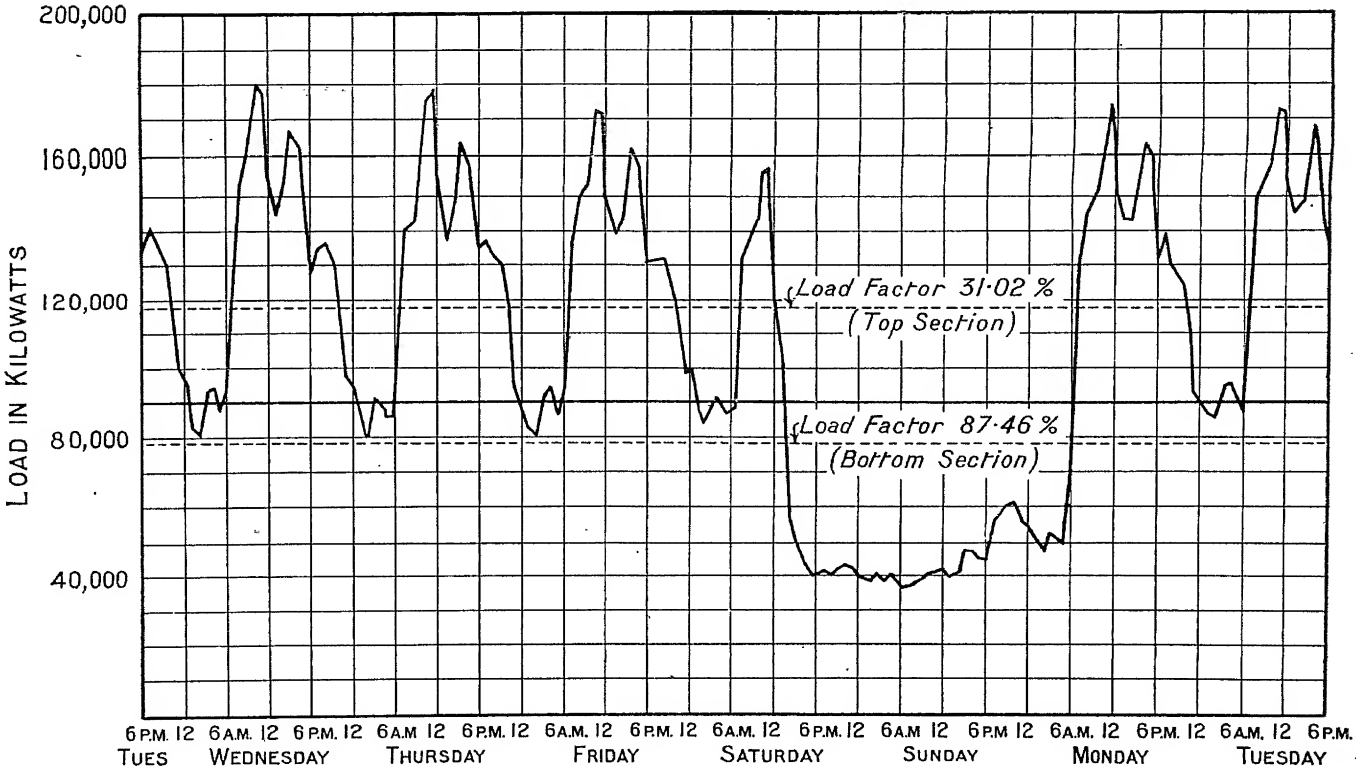

200,000
160,000
120,000
80,000
40,000
LOAD IN KILOWATTS
Load Factor 31·02 %
(Top Section)
Load Factor 87·46 %
(Bottom Section)
6 P.M. 12 6 A.M. 12 6 P.M. 12 6 A.M 12 6 P.M. 12 6 A.M. 12 6 P.M. 12 6 A.M. 12 6 P.M. 12 6 A.M 12 6 P.M 12 6 A.M. 12 6 P.M. 12 6 A.M. 12 6 P.M.
TUES WEDNESDAY THURSDAY FRIDAY SATURDAY SUNDAY MONDAY TUESDAY

FIG. 146.

advantages. The result is certainly a much smaller consumption of fuel over the whole system than would be the case for equivalent amounts of plant and load distributed among a larger number of smaller local stations, and also a lower cost of energy available at consumers' works and premises.

While the main output for a large district even in entirely virgin areas would always be generated in say two main stations, it might be found economical to generate some proportion of the load practically at the points of densest loads. This can only be determined by a close study of the requirements of any district—the probable nature of the load for industrial, domestic and transport purposes, the available sites for power stations, sources of fuel supply, cost of transmission, and particularly the sources of circulating water supply.

Location of Capital Stations.—It has often been urged that capital stations should be located at the pit's mouth or in close proximity to a colliery in order to secure the advantage of the lowest possible cost for coal delivered into the bunkers. This course would be perfectly sound provided that (*a*) a colliery or group of pits could be relied upon to maintain, without fail, the very large supply of coal required for a capital station; and (*b*) an adequate supply of condensing water was also available at the colliery site. Modern steam turbines are the most economical users of steam in existence when worked at a high vacuum, but the latter can only be obtained with a very large supply of cold water amounting to as much as 70 times the weight of the steam condensed. To secure maximum economy and lowest capital costs, it is essential that a capital station should be located at a site where there is an abundant natural supply of condensing water at a low temperature and capable of being utilized without undue cost for pumping. This consideration practically rules out colliery sites in Great Britain, and necessitates recourse to waterside sites located as favourably as possible in respect of coal supplies.

If such sites are on the coast, or on an estuary or large tidal river, no difficulties as to quantity of water arise. For proposed sites on an inland non-tidal river, however, accurate gaugings of the river flow have to be made, more especially of the dry

weather flow during periods of drought. In England there are many rivers which for nine months in the year have sufficient water flowing to deal with say 100,000 K.W. of almost continuous load without an undue rise in the temperature of the river to cause nuisance by overheating or rising vapour or damage to fishing; but for the remaining three months the flow falls off rapidly. In one case especially studied, only 30,000 K.W. could be effectively dealt with during three months of the year. Cooling towers for the remaining load have therefore to be provided, and although they add to the capital cost of the power house, they can be fairly and economically used for the quarter-year when the stream is low, and act as a reserve in any case.

There must be many such situations throughout the world, and the designer may well have to choose between a nearer station working on the lines described and a station on a more remote site where there is abundant condensing water the whole year round. In the latter case, the transmission costs (both capital and operating) may sometimes be so great as entirely to outweigh the costs of the supplementary and occasionally used cooling towers at the nearer station. These are among the problems which an expert power house designer has to solve and on the wise solution of which the future progress of a great undertaking may be largely dependent.

Design of Large Power Houses.—In view of the important part that will be played by well-placed capital stations in the development of electricity supply, it will be of interest to illustrate and briefly to describe a few typical designs of large power houses.

Power House Proposed for London. — The Engineering Board (of which the Author was a member) who advised the London County Council from 1905 to 1907 prepared designs for a capital station proposed to be built at Barking Creek for supplying in bulk to the Administrative County of London. The design was for a station of 120,000 K.W. capacity, and the general lay-out and sectional elevations are shown in Plate XV. The arrangement of the coal handling plant, of the self-contained boiler ranges, chimney and turbine as one complete

unit, as well as of the switchgear annexe may be specially noted.

Harbour Power House, Belfast.—A description of the salient features of the new Harbour power house for the City of Belfast, designed by Mr. John H. Rider, M.Inst.C.E., may be of interest particularly in regard to the arrangement of condensing culverts. A plan showing the general lay-out and various sectional elevations are illustrated in Plate V. (facing p. 88). The station is erected on what is known locally as "slob-land," i.e. reclaimed ground formed largely of dumps from the excavations and dredging out for the neighbouring docks, overlaid on a natural alluvial deposit. The foundations, water culverts, and buildings following the general lay-out of Mr. Rider were designed in detail by Mr. H. Cutler, M.Inst. C.E., the City Engineer of Belfast. This station is designed to accommodate two 6000 K.W. sets for light loads, three 12,000 to 15,000 K.W. sets, and ultimately 25,000 to 30,000 K.W. sets, and the building dimensions are arranged accordingly.

The boiler house is arranged at right angles to the engine-room and contains a basement with ash extraction plant, and an economiser floor above the boilers. The boilers are set out in two rows, each pair being a self-contained unit with balanced draught, superheaters, economisers, forced and suction draught fans and steel chimney shaft. The boilers are of the marine water tube type with metal casings lined with fire-brick. Each boiler is capable of evaporating as a continuous economical daily load not less than 55,000 lb. of water per hour from and at 212° Fahr., or 48,000 lb. at a steam pressure of 235 lb. per square inch above atmosphere and with feed water at 130° Fahr., this duty being accomplished with Scotch small coal having a calorific value of 10,500 B.Th.U. per lb. as fired. The superheaters are arranged so that a maximum temperature of 250° Fahr. may be added to that of the saturated steam at 235 lb. gauge pressure. There is a motor-driven forced-draught fan for each boiler capable of delivering the air necessary for complete combustion at a pressure sufficient only to carry the air through the fuel bed when the boiler is working up to the above-mentioned duty. A motor-driven suction-draught fan for each

boiler is fixed on the economiser floor and each fan is sufficient to carry off the whole of the products of combustion of one boiler when working on 0·4 inch water gauge. Further details of this plant were given in a previous chapter (p. 89).

The circular steel shaft 70 feet in height (or 100 feet above grate level) has an internal diameter of $9\frac{1}{2}$ feet and is constructed of $\frac{1}{4}$ inch steel plate and fitted with a sheet steel mid feather extending to 6 feet above the flue inlets.

The economiser fitted to each boiler contains 416 tubes, each 11 feet 6 inches long by $4\frac{9}{16}$ inches outside diameter, fitted with motor-driven scrapers and enclosed within double steel plate casings spaced 4 inches apart and filled with silicate of magnesia.

The boiler feed pumps are of the multi-stage rotary type, each driven by a 3-phase motor and capable of delivering continuously any quantity of water up to 20,000 gallons per hour against a total head equivalent to a pressure of 250 lb. per square inch when working at a constant speed of 1460 R.P.M., the water being delivered to the pumps under a 4 feet-head and at a temperature of about 150° Fahr.

The turbo-alternators are of the horizontal impulse type with a terminal pressure of 6600 volts between phases at a periodicity of 50 cycles per second and a speed of 3000 R.P.M. The exciter voltage is 220 volts at full load. The turbines are supplied with steam at a gauge pressure of 225 lb. per square inch at the stop valve, superheated to a total temperature of 650° Fahr., and they are designed to work against an absolute back pressure of 1 inch mercury column—that is a vacuum of 29 inches with the barometer at 30 inches. Each alternator is provided with an air washing plant and filter, fixed close to the external wall of the engine-room, which is of sufficient capacity to deal effectively with at least 25,000 cubic feet of air per minute.

The condensers for the 6000 K.W. sets were specified to have not less than 11,000 square feet of cooling surface. They are capable of maintaining an absolute back pressure not greater than 1 inch mercury column at continuous full load of the turbine when supplied with not more than 9000 gallons of circulating water per minute at a temperature of 55° Fahr., and

with 15 per cent. of the tubes blocked off, the cooling water being sea water pumped from the harbour.

Each dry-air pump is of the rotary type, operated by hurling water. The hurling water is energized by a centrifugal pump which draws the water from a sealing tank and delivers it to the rotary air pump. The latter is driven by the hurling water which it converts into high velocity jets; these jets trap the air which is delivered, with the hurling water, into the sealing tank. The hurling water is thus circulated continuously without renewal. It is kept at a low temperature by means of a cooler provided in the sealing water tank, the cooler coils being connected across the main circulating water pipes. The arrangement allows the use of fresh water in the air pumps, and obviates the necessity for a costly supply of fresh make-up water.

The condensate pumps are of the multi-stage centrifugal type, and they deliver the condensate through Lea Recorders to hot wells in the feed pump room. The condensate and hurling water pumps are mounted upon common bedplates, and are driven by multipolar, direct current, shunt wound motors.

On reference to Plate V. it will be seen that the circulating water pumps are installed in a separate pump house which contains the main water channels. A separate circulating water system is provided for each turbo alternator.

The sea end of each main channel is provided with a self-cleaning screen, to prevent the ingress of leaves, seaweed, or other flotsam.

An interesting feature in connection with the circulating water system is the provision between the main water channels of suction and delivery sumps, which are connected to both channels. Motor operated sluice gates are provided on each side of each sump. The sluice gates are mechanically connected in pairs, and so arranged that if a suction sump is connected to one main channel, the corresponding discharge sump is connected to the other main channel. By these means a reversal of the direction of flow in the main channels may be quickly brought about at each change of tide. The arrange-

ment eliminates any possibility of the channels becoming silted up with mud or sand.

The arrangement of the coal handling plant is clearly shown on Plate V. Two electrically operated Portal type travelling jib cranes are provided on the jetty, by means of which the coal is grabbed from the colliers or barges, and delivered to receiving hoppers. The coal passes from these hoppers through crushers and fillers to conveyors, which deliver it to the hoppers of the coal weighing plant; then by further conveyors to the main storage bunkers, from which the coal is conveyed to the overhead service bunkers in the boiler house.

The H.T. switchgear is housed on two floors over the circulating water pump house. A description of the switchgear with diagram is given in Chapter X. The H.T. switchgear control panels are installed on a high level platform at the end of the engine-room. Below this a second platform is provided which carries the auxiliary switchgear for the control of the station rotaries and auxiliary plant circuits.

The engine-room is served by an electrically-driven 50-ton travelling crane. The circulating water pump house is served by a 5-ton hand crane.

The railway siding is carried through the pump house, engine-room, and workshop, thus affording convenient unloading facilities.

It will be seen that the lay-out of the first section of the station is such that extensions can conveniently be carried out in sections of any capacity from 25,000 K.W. to 50,000 K.W. each.

Newport Power House, Melbourne.—The power station which supplies the Melbourne suburban system of the Victorian Government railways was designed by Messrs. Merz & McLellan, Consulting Engineers, Westminster. The station is shown in plan on Plate XVI. and various sectional elevations are given on Plate XVII. The site at Newport, which occupies some 36 acres and is mainly situated on basaltic rock, has been adapted so that two stations can be erected side by side in order that full advantage can hereafter be taken of any further developments in power house design without interfering with the lay-out of the present station.

The first station is designed to contain six 12,500 K.W. turbo alternators (3-phase, 25 cycle, 3300 volts), running at 1500 R.P.M., two sets serving as spares for standby and overhaul. The turbines are of the Parsons reaction type with divided cylinders, the high pressure being of the single flow type and the low pressure of the double flow type. At a power factor of 0·95, four of the turbo alternators have an economical output of 10,000 K.W., a maximum continuous output of 12,500 K.W., and an overload capacity of 14,000 K.W. for short periods, the corresponding figures for the other two sets being 12,500 K.W., 14,000 K.W., and 15,000 K.W.

Each prime mover is treated as far as possible as an independent unit; each turbo alternator has its own oil cooled step-up transformer to 20,000 volts, and an auxiliary transformer reducing to 440 volts for operating the circulating pumps, oil cooler, air filter pumps, etc. The transformers are installed in a separate chamber outside of the engine-room, and between these chambers are others which contain the air filters, neutral resistances, and other details.

The guaranteed steam consumption of the turbo alternators, including transformer losses, with a steam pressure at the stop valve of 200 lb. per square inch, a steam temperature of 600° Fahr., a vacuum of $28\frac{3}{4}$ inches of mercury, and a voltage of 20,000 is as follows at the economical output: 12 lb. per K.W.H. for the 10,000 K.W. sets, and 11·35 lb. for the 12,500 K.W. sets.

The engine-room is equipped with a 60-ton electrically operated crane and a 4 to 15 ton auxiliary hand crane.

There are six twin condensers of the Contraflo type, each with a surface of 22,000 square feet. The circulating pumps with a capacity of 14,000 gallons per minute are situated in a central position as shown in Plate XVI., and in the longitudinal section C-C on Plate XVII. This forms a novel feature of the design. The water supply of the pumps is in duplicate, and the pumps are so arranged that four of them can be supplied from each half of this duplicate system; this suffices for the full load output of the station, and repairs and maintenance of the circulating water system can thus be carried out at any time. Special screening pits are arranged in the suction culverts.

The two boiler houses are built at right angles to the engine-room, each being complete with its own coal store and coal handling machinery, and between the two boiler houses there is a space which is occupied by a general purpose building containing stores, water storage tanks, test tanks, laboratories, workmen's accommodation, etc. Each boiler house contains 12 Babcock & Wilcox marine type water-tube boilers, the particulars of which are as follows: heating surface 6725 square feet; grate area 168 square feet; steam pressure 210 lb. per square inch; normal rating with feed water at 90° Fahr., and when fired with coal having a calorific value of 11,000 to 12,000 B.Th.U. per lb., 30,000 lb. per hour. The boilers are fitted with chain grate stokers, superheaters raising the temperature of the steam to 600° Fahr., economisers having a heating surface of 2880 square feet per boiler and Davidson's "Sirocco" mechanical fans on an upper deck, and steel chimneys. The whole of the condenser, boiler feed, transformer, air cooler, turbine oil cooler, and air filter auxiliaries are placed on the same level in the basement and are easily accessible, the basement being well lighted and free from obstructions. The boiler equipment is provided with suction ash plant which also removes the soot from the economisers.

The mechanical coal handling appliances are such that the fuel which is delivered in railway trucks is deposited either in the overhead bunkers or in the coal store, or taken from the storage yard (which holds 10,000 tons for each boiler house) and delivered to the bunkers. A jib crane is used to deposit the coal in the coal yard, and this can deliver coal direct from the store to the boiler house conveyors without using the yard conveyor. The whole lay-out is such that manual labour is reduced to a minimum.

The switch house is parallel with the engine-room and at a short distance away from the main building, as shown in the plan, there being no attempt to provide ready communication between the switch house and engine-room staff except by telephone and telegraph. The main bus bars are divided into two sections by a section switch, each railway substation being fed from both bar sections. Mechanical interlocking has been

Fig. 165

adopted throughout so that operators cannot obtain access to live conductors. The oil switches are operated by remote control and the operating mechanism has a wall separating it from the oil switch so that it can be examined and cleaned without danger. There are no windows in the switch house, one side of each switch cell being open to the outside air so that excessive air pressures resulting from a heavy short circuit may be immediately relieved. Precautions are taken to prevent trouble from rain or birds, etc.

The 3-phase oil switch will safely open a short circuit on a system controlling power up to 140,000 K.V.A. The alternator equipments are fitted with Merz-Price protective gear, the feeder equipments having "split-conductor" protective gear. Each alternator is provided with an emergency control pillar and a load indicator fixed in the engine-room.

The control room is situated at the end of the switch house and is fitted with a gallery. In this is centred the control of the main switches of the alternators and transmission system, and all electrical operations throughout the entire transmission and conversion system are directed from this room. A large diagram showing the position of all principal switches on the system covers one wall of the control room. A view of the control room is shown in Fig. 147 and a general view of the power station taken from the river Yarra is given in Fig. 148 in which the right-angle boiler house, pump room, main engine-room, transformer house and switch house (with control room) are successively shown in elevation.

Dalmarnock Power House, Glasgow.—The Dalmarnock station of the Glasgow City Corporation is one of the most modern examples of a large power house, and was designed by Mr. W. W. Lackie, C.B.E. The site is 13½ acres in extent and is bounded on the south by the river Clyde and on the west by the Caledonian Railway. There are, therefore, the fullest facilities both for condensing water and for coaling purposes. The ultimate load on the power house will be 200,000 K.W., and a ground plan showing the general lay-out is given in Plate XVIII.

The subsoil is quite suitable for heavy weights, but a concrete

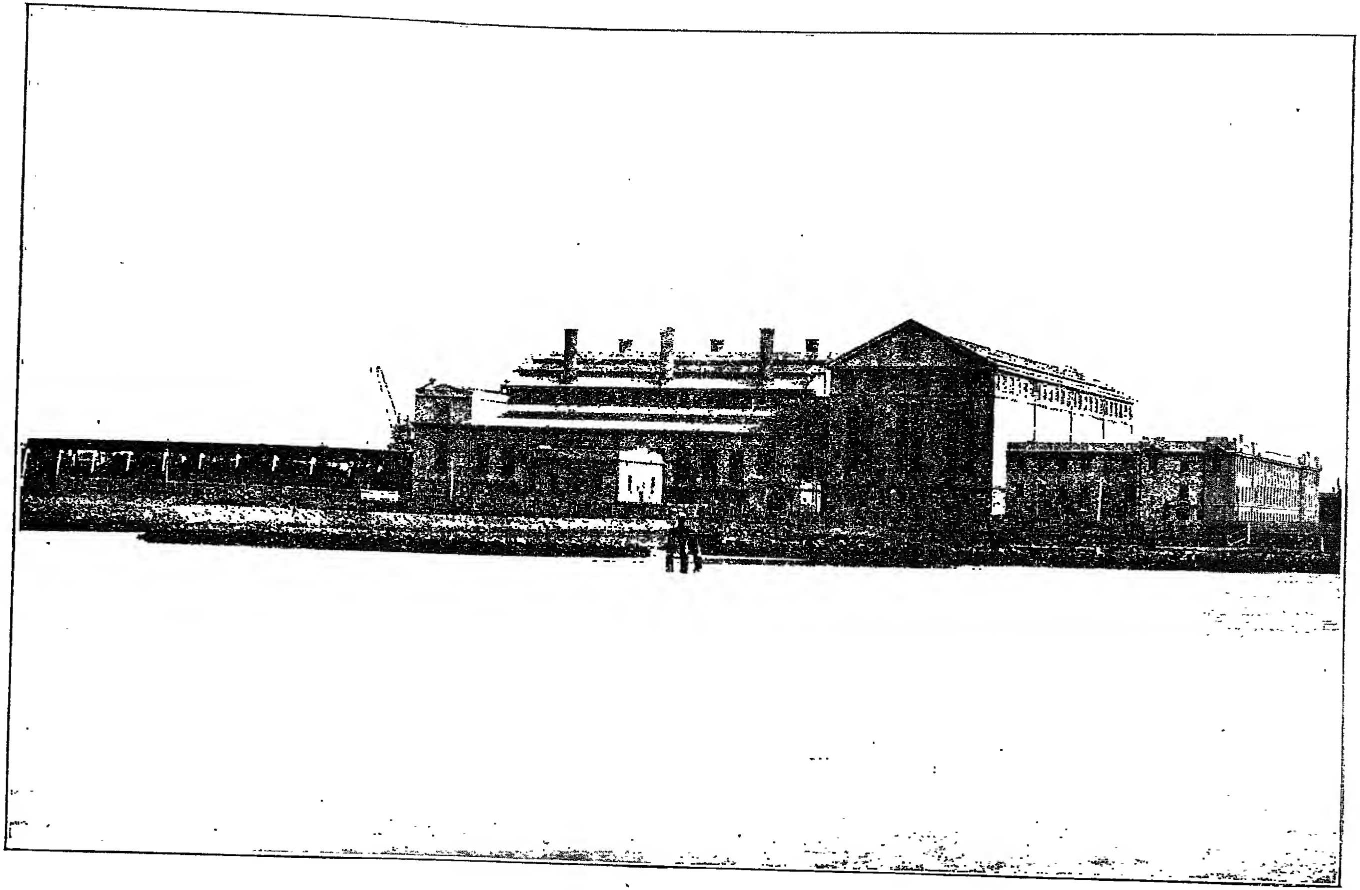


FIG. 148.

raft 5 feet thick was laid over the entire area of the boiler house, turbine room, and switch house, so as to ensure sound foundations for the turbo alternators. The buildings are of reinforced concrete.

Coal is brought direct from the collieries by rail, and at the power house sidings each truck passes over a weighbridge to a tipping platform and is then emptied into a hopper by an electrically operated ram. Coal crushers are also provided. The coal passes from the hopper into a bucket conveyor and thence to a distributing centre from which other conveyors take

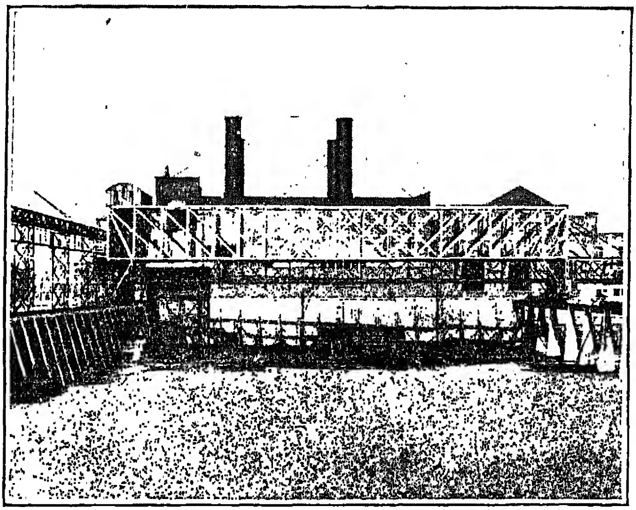


FIG. 149.

it either to the boiler house bunkers or to the coal store. A travelling gantry with grab and a bucket conveyor are provided to handle the stored coal at the rate of 100 tons per hour. The coal store and travelling gantry are shown in Fig. 149.

The boiler house is of three storeys. On the ground floor there are the ash removal hoppers and eight 35 B.H.P. forced draught fans and motors. The boilers are on the first floor, and four 125 B.H.P. induced draught fans, economisers, coal bunkers, and hot wells are on the second floor.

Each boiler house contains eight Babcock & Wilcox marine

type boilers arranged in two rows of four. Each boiler has three chain grate stokers, a superheater and an economiser. Under balanced draught, the maximum evaporative capacity of each boiler is 62,000 lb. per hour, the normal evaporation being 50,000 lb. per hour. The working pressure is 275 lb. per square inch, and the total temperature of the steam 700° Fahr. Three boilers are sufficient to run one turbine, the fourth boiler being in reserve. There is one steel chimney for each pair of boilers, and each chimney has a grit and dust settling chamber at its base.

The equipment of each boiler comprises automatic coal weighing machines, steam flow meters, thermometers, CO_2 indicator and pressure and draught gauges. The ashes gravitate from the boiler ash-pits into hoppers whence they are removed by suction ash plant.

The first turbine room will contain five sets (3-phase, 6500 volts, 25 ∽), the maximum continuous output of each set being 18,750 K.W., and the most economical load being 15,000 K.W. The steam consumption at the most economical load is guaranteed not to exceed 10 lb. per K.W.H. with a vacuum of 29·1 inches of mercury (Bar. 30 inches). The speed of the turbines is 1500 R.P.M. There are also two 500 K.V.A. geared turbo alternator sets, the turbines running at 3500 R.P.M. and being geared to 440 volt alternators running at 750 R.P.M. which are used for driving the auxiliary operating plant in the power house. The turbine room is equipped with an electrically operated 75-ton travelling crane.

Each main set is fitted with a condenser having a cooling surface of 26,000 square feet, and with circulating pumps each capable of delivering 22,500 gallons per minute through each condenser. The average velocity of the water through the condensers is 4·9 feet per second.

The air pumps can extract 60 lb. of air per hour and each set has a standby. The wet pumps deliver the condensate through a Lea recorder and thence it is lifted through a feed water heater to the hot wells. The air filter for each alternator deals with 70,000 cubic feet per minute at 0·6 inch water gauge.

The circulating water is drawn from the river Clyde through

reinforced concrete culverts, fitted with main sluice gates and screening plant so as to remove leaves and other flotsam and as much suspended matter as possible. A general view of the first section of the power house showing the condensing water inlet is given in Fig. 150.

The switch house contains the water cooled step-up transformer for each alternator (6500/20,000 volts) and the general switch equipment. These step-up transformers are in single-phase units each giving 7800 K.V.A. and being provided with

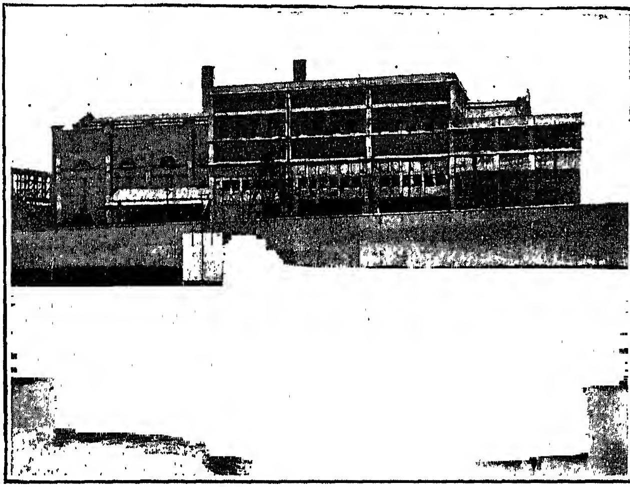


FIG. 150.

a third winding from which the auxiliaries may be ordinarily supplied at 440 volts.

All the switchgear is of Reyrolle's ironclad construction and is of novel design and includes five main alternator switches, eighteen feeder switches, two coupling and two sectionalising switches. The estimated rupturing capacity of each switch is 1,500,000 K.V.A. The bus bar pressure is 20,000 volts. All the switches are operated from a general control room shown in Fig. 151.

A large 250 volt storage battery (125 cells) is also installed. This has a capacity of 3000 ampere hours on a 10-hour rating and is fixed in the basement of the switch house. This battery

is required for emergency excitation of the main alternators, switch house travelling crane, and emergency station lighting.

Below the control room there are also two 100 volt batteries

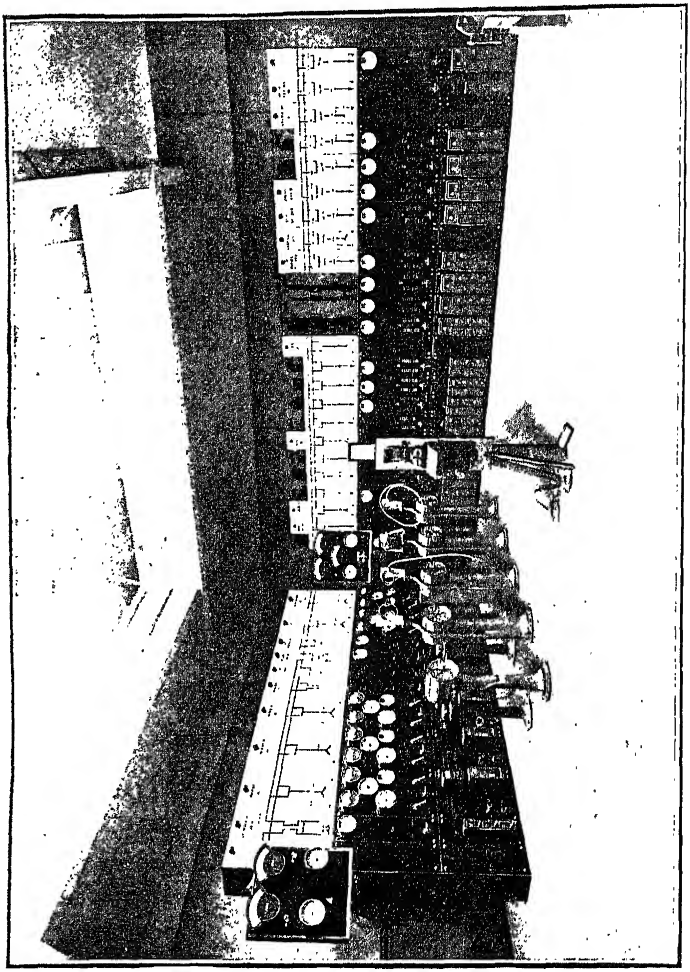


FIG. 151.

(each of 55 cells), each having a discharge of 250 ampere hours at one hour rating, for the operation of the main switches, controls, and station telegraphs. These batteries are charged by motor generators in duplicate, each consisting of a 440 volt

induction motor and direct-current generator giving 650 amperes at 225 to 325 volts and another set 100 amperes at 75 to 150 volts.

The neutral point of the 20,000 volt system is earthed through a water resistance able to carry 500 amperes at 11,500 volts.

Capital Costs of Large Power Houses.—Although any discussion of the capital costs of large power houses under present-day conditions is apt to be misleading owing to the continual fluctuations in the prices of materials and plant and in rates of wages, some indication in pre-war terms may be of assistance. In order to arrive at the approximate cost of buildings and plant in Great Britain at the present time (1920), it is necessary to apply a multiplier, which may be taken as from 2·5 to 2·8, to the corresponding costs prevailing in 1914.

Reference may be made in the first place to the carefully prepared estimates (1906) of the capital cost of the large power house proposed to have been erected at Barking Creek for the supply of London. The figures are set out in Table No. CII.

TABLE CII.

PROPOSED POWER HOUSE AT BARKING: ESTIMATED COST (1906).

(Rated output 120,000 K W.; Overload capacity 150,000 K.W.).

Items.	Capital cost.	Cost per K.W.	
		Rated load.	Overload.
	£	£	£
Land	50,000	0·41	0·33
Buildings	344,000	2·87	2·30
River work and pier	102,000	0·85	0·68
Coal and ash plant	59,000	0·49	0·40
Boilers and economisers . . .	199,000	1·66	1·33
Pipework and pumps	105,000	0·88	0·70
Turbo-generators and condensers . .	430,000	3·58	2·86
Switchgear, etc.	67,000	0·56	0·44
Engineering expenses and contingencies	115,200	0·96	0·77
Total	£1,471,200	£12·26	£9·81

The following estimates (in Tables CIII. and CIV.) were prepared by the Power Sub-Committee of the Nitrogen Products Committee of the British Ministry of Munitions and appear in full in the Final Report of the Committee published early in 1920. They are based upon the latest pre-war figures, and give

the capital and operating costs of a station having an installed capacity of 125,000 K.W. and a maximum load of 100,000 K.W. This capacity was selected by the Power Sub-Committee as representing a reasonable size of station for the production of power at the least possible cost under British conditions for nitrogen fixation or other purposes for which a very high annual load factor is essential.

The details of the station are as follows:—

Plant installed at normal rating	125,000 K.W.
Maximum effective load at normal rating . .	100,000 K.W.
30 boilers installed . . .	1,500,000 lb. steam per hour.
24 boilers working . .	1,200,000 lb. ,, ,, ,,
Size of turbo-alternators	25,000 K.W. each.

The estimate of capital cost is as given in Table No. CIII.

TABLE CIII.

ESTIMATED CAPITAL COST OF 100,000 K.W. STATION.

(Pre-war basis.)

Items.	Capital cost.	Cost per K.W.	
		Installed.	Maximum load.
	£	£	£
(a) Land for complete station . . .	20,000	0·16	0·200
(b) Buildings and foundations, coal silos and transporters, railway sidings, roads, etc.	187,500	1·50	1·875
(c) Coal and ash handling plant . .	30,000	0·24	0·300
(d) Boilers, superheaters, reheaters, feed heaters, mechanical stokers, induced draught plant, chimneys, etc. . .	225,000	1·80	2·250
(e) Turbo-alternators and exciters, surface condensers, air pumps and auxiliaries	312,500	2·50	3·125
(f) Steam and water piping, circulating and feed pumps, air pumps, strainers, etc.	75,000	0·60	0·750
(g) High and low tension switchgear, reactances, etc.	100,000	0·80	1·000
(h) Engineering supervision, inspection, contingencies, etc.	76,000	0·60	0·760
Total	£1,026,000	£8·20	£10·26

The annual working expenses for the station operating at a load factor of 95 per cent. were estimated from known facts on the bases of—

Maximum load	100,000 K.W.
Calorific value of coal as fired .	12,500 B.Th.U. per lb.
Thermal efficiency of boilers with superheaters and economisers .	80 per cent.
B.Th.U. per unit output . .	20,000
Cost of coal	10/- per ton.

to be as given in Table No. CIV.

TABLE CIV.

ESTIMATED COST OF GENERATION AT 100,000 K.W. STATION.

(Pre-war basis.)

Items.	Load factor = 95 per cent. K.W. year = 8322 hours. Units = 832,200,000.		
	Annual expenses.	Per unit.	Per K.W. year.
	£	d.	£
Salaries and wages . .	14,000	0·0040	0·140
Oil, stores and sundries .	10,000	0·0029	0·100
Repairs and maintenance .	30,000	0·0086	0·300
Coal: 594,430 tons . .	297,215	0·0857	2·972
Capital charges (see below) .	91,327	0·0263	0·913
Total	£442,542	0·1275*d.*	£4·425

The annual capital charges upon the items specified in Table No. CIII. are made up as follows: (i) 4½ per cent. interest on capital, taken as a fair average over a period of years; (ii) 2½ per cent. depreciation on buildings, etc. (item *b*) and upon the corresponding proportion of contingencies and engineering fees (item *h*); and (iii) 5 per cent. depreciation on the remaining capital (items *c* to *g*) and upon the corresponding proportion of contingencies and engineering fees (item *h*). No depreciation has been taken on land and its proportion of contingencies and engineering fees, and no sums are included for insurance, imperial taxes, or local rates.

As a last example, the figures for the Dalmarnock power

house, Glasgow, are set out in Table No. CV. In this case the land was acquired in 1910 and the constructional work commenced in 1914, so that the capital cost for the first section having an installed capacity of 93,750 K.W. and a maximum continuous output of 75,000 K.W. is partly on a pre-war and partly on a war and present-day basis.

TABLE CV.

CAPITAL COST OF DALMARNOCK STATION.

(Installed capacity, 93,750 K.W.; Maximum load, 75,000 K.W.).

Items.	Capital cost.	Cost per K.W. of maximum load.
	£	£
Land	64,501	0·86
Foundations	54,329	0·72
Coal handling plant	30,000	0·40
Buildings	141,888	1·89
Boiler house plant	347,200	4·65
Turbine room plant and step-up transformers	535,778	7·15
Switchgear	67,970	0·90
Total	£1,241,666	£16·57

If adjusted to present-day conditions (1920), the above figures would represent an approximate outlay of £24 to £25 per K.W. of maximum output.

Choice of Number and Size of Units.—In well-designed power houses, the plant is so split up as to enable each set to be kept running at as high a plant load factor as possible. The result is a lower consumption of steam and coal. In small installations it is often worth while to graduate the sizes of the plant so as best to fit in with the variable load throughout the day. Thus, while six to eight sets are advisable for the larger stations, there are, of course, many cases of smaller stations where a less number is required, and then it is that graduated sizes should be adopted. The following Table No. CVI. gives a suggestive analysis of the sizes of plant which may be selected, but the figures must be taken with great caution, since each problem must receive careful expert consideration.

TABLE CVI.

NUMBER AND SIZE OF UNITS FOR POWER HOUSES.

Total maximum demand on power house.	Total plant installed.	Percentage of reserve plant.	Number of sets.	Sizes of units suggested.
K.W.	K W.	per cent.		
100,000*	120,000	20	6	6 × 20,000 K.W.
50,000*	60,000	20	6	6 × 10,000 ,,
20,000	26,000	30	6	4 × 6,000 ,, + 2 × 1000 K.W.
10,000	13,000	30	6	4 × 3,000 ,, + 2 × 500 ,,
5,000	7,000	40	6	4 × 1,500 ,, + 2 × 500 ,,
2,500	3,500	40	5	3 × 1,000 ,, + 2 × 250 ,,
1,000	1,500	50	4	2 × 500 ,, + 2 × 250 ,,
500	750	50	3	3 × 250 ,,
			or 4	or 2 × 250 ,, + 2 × 125 ,,

* Capital stations working on high annual load factor in parallel with supplemental low load factor local stations.

For high load factor stations, the overload capacity of the plant cannot be relied upon except for short period emergencies. It is assumed that the capital stations cited in the above table could rely at least upon an aggregate of reserve plant in the supplementary local stations equal to one of the sets in the former station.

It is impossible really to lay down any specific rule because local requirements are so variable, and the proportion of large units to small units to be installed in a given case must be determined by the character of the assumed daily load curve. A typical output curve for an English town is shown in Fig. 152.

In the case of direct-current power houses the supply would probably be given by a 3-wire system, and it is advisable to wind all the generators for the pressure across the outers, to balance the system by a 3-wire balancer, and to charge batteries (if any) by motor-driven boosters. This avoids the necessity for installing small generators at half-pressure, i.e. that between an outer conductor and the neutral or middle wire. In the generality of small isolated plants, however, provision has to be made for dealing with very light night loads.

When the units are fairly well proportioned, so as to step

up and down with the rising or falling load, their rated load should correspond to the most economical point on the steam consumption curve. For well-designed throttle-governed reciprocating engines with an auxiliary variable cut-off, the curve is fairly flat between $\frac{3}{4}$ and $1\frac{1}{4}$ load. Where, however, the load is continually varying, as in power houses for small tramways or for mines with winding sets and haulage, then it will be found that any given engine should be set so as to give the

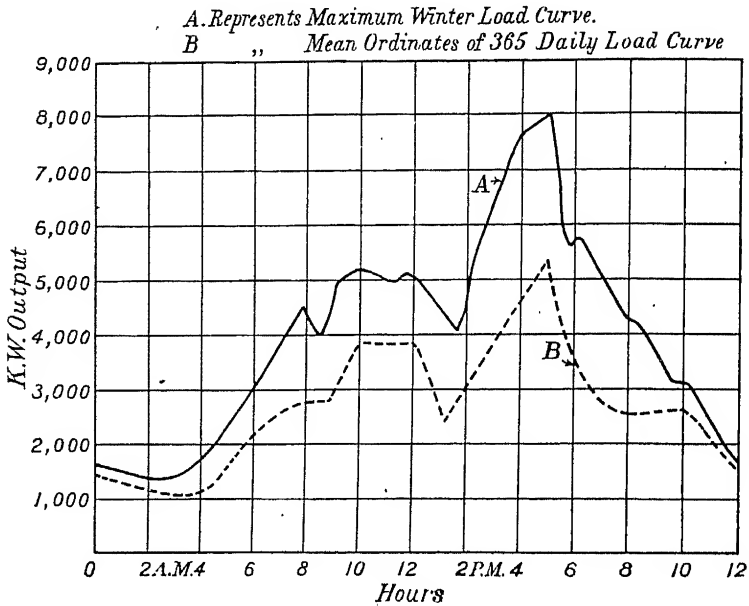


Fig. 152.

greatest economy at $\frac{3}{4}$ load, as that will be the average point at which it will run, the peaks taking the engine load up to the rated output or beyond.

A typical curve of an ordinary tramway load is given in Fig. 153, from which it will be seen that the mean load is only $\frac{5}{7}$ of the maximum peak recorded.

In this case, the division of plant is as follows, namely: four sets each of 5000 K.W., and four sets each of 3500 K.W., making a total of 34,000 K.W. normal rating.

The curve for an integrated daily load on the power house of a large system of mines for which the Author was adviser is given in Fig. 154.

The plant installed in this case consisted of three sets each of 1150 B.H.P. (or 750 K.W.), a total of 2250 K.W.

The Dalmarnock station at Glasgow and the Newport station at Melbourne provide interesting examples of the use, in large power houses, of units designed to operate most economically at 80 per cent. of their maximum continuous output. An installation of such units is characterised by considerable flexi-

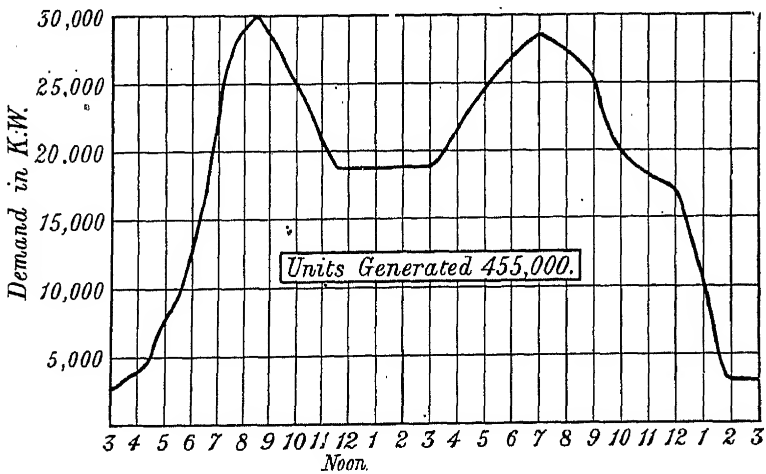


FIG. 153.

bility as will be seen from the following figures. The first section of the Dalmarnock station is designed for five units, (one being a spare), each having a most economical output of 15,000 K.W., a maximum continuous output of 18,750 K.W., and an overload capacity of 21,000 K.W. for short periods. Normally, with four sets running, the output would be 60,000 K.W., but an output of 75,000 K.W. could be maintained continuously and an output of 84,000 K.W. for short periods. If one of the sets went out of action, the remaining three could maintain an output of 56,250 K.W. continuously (practically the normal output of the four sets), and an output of 63,000

K.W. for a short period while the spare set was being brought into operation.

Smaller Power Houses: Bulk Supply.—An engineer is often called upon to determine whether economy is to be gained by installing an independent power house, driven either by steam or gas or oil engines, to supply the needs of some factory or shipyard or other works; or whether a supply should be taken from some public authority to a substation erected on the works

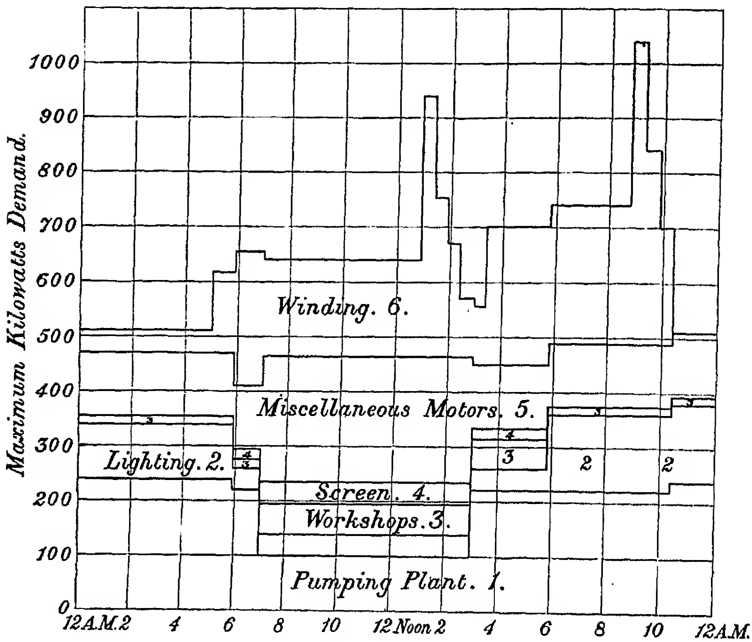


FIG. 154.

in question. In this connection, it must not be overlooked that in many works shavings and other combustible refuse have to be disposed of, and may represent a considerable proportion of the total fuel needed for power purposes. Again, in the case of factories where large quantities of steam have to be raised for heating and other purposes, the use of exhaust turbines or back-pressure reciprocating engines may furnish a very economical means of meeting the power requirements of the factory, as indicated in a previous chapter (p. 223).

The economic possibilities of small power houses and the order of the prices to be reached by supply authorities to permit of the successful competition of bulk supplies were dealt with somewhat fully by the Author in his paper on "The Supply of Electricity for Industrial Purposes" read before the Institution of Electrical Engineers, England, in 1908 ("Journal," Vol. 40, p. 288 *et seq.*).

In that paper and in the ensuing discussion, the matter was fully threshed out, and it was shown (and was not disputed) that for small independent power plants ranging from 100 to 500 H.P., the relative costs of energy measured at the power house switchboard were generally as set out in Table No. CVII. These figures were compiled by the Author from actual results and represented ascertained costs of commercial working at the date in question.

TABLE CVII.

Ascertained Costs per Unit Generated (Pre-war).

(Independent Power Houses : 100-500 H.P. Installed.)

Annual load factor.	Type of power house.			Average cost per unit generated.
	Gas engine (producer gas).	Oil engine.	Steam.	
per cent.	*d.*	*d.*	*d.*	*d.*
10	1·273	1·007	1·086	1·122
15	0·944	0·778	0·811	0·844
20	0·760	0·656	0·673	0·696
25	0·670	0·584	0·590	0·615
30	0·596	0·536	0·534	0·555
35	0·540	0·498	0·494	0·511
40	0·502	0·469	0·464	0·478
50	0·447	0·430	0·421	0·433
60	0·406	0·404	0·393	0·401

Based on : Anthracite at 22*s*. per ton ; bituminous coal at 10*s*. per ton ; oil (petroleum residue) at 42*s*. per ton ; water for cooling purposes or boiler feed at 6*d*. per 1000 gallons ; repairs and lubricating oils and stores taken from actual cases ; depreciation and interest on capital taken at 10 per cent.

The above costs refer to pre-war conditions in Great Britain, but the proportions would hold good for other countries.

Before a proper comparison can be made between the local

costs at an independent power house and the cost of an alternative bulk supply, many factors have to be taken into account. In the first place, the units sold by the bulk supply authority represent units metered at the switchboard of the local power house. Allowances have to be made for the units lost in conversion or transformation of the bulk supply as the case may be, for the capital charges on the requisite transforming plant and extra switchgear, for wages (a considerable reduction, of course, on the wages for generating an equivalent supply at the local power house), and for repairs and maintenance. A proportion of the charges on the local system in respect of distribution, rates and taxes, management, insurance, and capital charges has also to be added before the final and comparable figure is obtained. When all these allowances have been made, it is found that the bulk authority's figure is, of course, considerably enlarged.

Where there are existing small power stations some of which are unfavourably situated for low generating costs, it would probably pay in some cases to extend one of the better placed stations only, and to supply the others in bulk therefrom, rather than to extend each small station from time to time. On the other hand, when once a small station has been built and the expenditure incurred, then and so long as the system is kept within defined limits of extension, the *extra* working costs incurred by an addition to the station are often less than those of any commercially feasible bulk supply. These matters were referred to by the Author in his Presidential Address to the Institution of Electrical Engineers in 1914, and the changed economic conditions since that date have added to their importance as factors to be considered in the development of electricity supply.

Capital Costs of Smaller Power Houses.—A few typical examples may be given of the estimated or ascertained costs of small power houses under pre-war conditions. The relation of the figures to present-day costs has been indicated in a previous paragraph dealing with the capital costs of large stations (p. 403).

An estimate, based on the latest pre-war prices, for a steam power station having an installed capacity of 6250 K.W. and a

maximum load of 5000 K.W. was prepared by the Nitrogen Products Committee of the British Ministry of Munitions and is set out in Table No. CVIII.

TABLE CVIII.

ESTIMATED CAPITAL COST OF 5000 K.W. STATION.

(Pre-war Basis.)

Items.	Capital cost.		
	Total.	Per K.W. installed.	Per K.W. of maximum load.
	£	£	£
Land	2,500	0·4	0·50
Five turbo alternators (1250 K.W. each) with condensing plant, etc.	25,000	4·0	5·00
Four water-tube boilers (25,000 lb. [illegible] superheaters, [illegible], etc. . .	18,750	3·0	3·75
Steam and water piping, tanks, etc.	5,000	0·8	1·00
Feed and circulating pumps . .	1,560	0·25	0·31
Auxiliary plant: two sets of 300 K.W. each, one a steam set and the other a rotary converter .	4,600	0·74	0·92
Main and auxiliary switchgear and machine connections . . .	4,370	0·7	0·87
Cranes and lifting tackle . .	1,600	0·25	0·32
Coal and ash handling plant and coal storage	6,250	1·0	1·25
Buildings and foundations . .	15,600	2·5	3·12
Engineering and contingent expenses at 7·5 per cent. . .	6,050	0·96	1·21
Total . . .	£91,280	£14·60	£18·25

The estimate in Table No. CIX. was given by Andrews & Porter for a gas engine power house equipped both with ammonia recovery producers and with non-recovery gas producers, the former dealing with that portion of the load having the highest load factor and accounting for about 71 per cent. of the total consumption of coal. The installation comprised seven gas engine generators, each having a rated output of 1450 K.W. and representing a total capacity of, say, 10,000 K.W. Allowing two sets in reserve, or one in reserve and one under repair, as would be reasonable in a commercial station of this character, the available output is therefore, say, 7500 K.W.

TABLE CIX.

ESTIMATED CAPITAL COST OF 10,000 K.W. GAS POWER HOUSE.

(Pre-war Basis.)

Items.	Total cost.
	£
Seven gas engines, generators, air compressors, gas, water, air, and exhaust pipes, and all auxiliaries erected	98,000
Four ammonia recovery producers, erected complete, with superheaters, blowers, cooling and washing towers, centrifugal cleaners, scrubbers, ammonia absorber, and all pipe work .	18,490
Duplicate blower, washer, and centrifugal cleaner . . .	3,780
Four non-recovery producers, with scrubbers, etc. . . .	10,340
Steam-raising plant, economizers, feed pumps, etc. . . .	4,850
Water-cooling towers, pumps, and water softener . . .	1,990
Buildings, foundations, etc.	24,275
Overhead travelling crane	1,250
Steel structural work, coal bunkers, coal and ash conveying plant	6,150
Exciters, battery, switchgear, and connections to generators .	7,750
Total	£176,875

The above figure represents a cost of £23·6 per K.W. of maximum load, and the ground space occupied by the power

TABLE CX.

ESTIMATED CAPITAL COST OF 22,500 B.H.P. GAS POWER HOUSE.

(Pre-war Basis.)

Items.	Cost per B.H.P.	Total cost.
	£	£
Nine twin tandem [illegible] engines, each to develop 2500 B.[illegible]	5·625	112,500
Nine 50-cycle 5000-volt 3-phase alternators direct coupled to engines	1·300	26,000
Gas [illegible] [illegible]vers, and exhaust ga[illegible] to producers .	3·75	75,000
Centrifugal type gas-cleaning plant	0·600	12,000
Engine house 470′ × 80′, steel skeleton frame, with brick panels, fitted with 20-ton crane . . .	1·200	24,000
Foundations for gas engines and engine house (14,000 cubic yards)	0·700	14,000
Cooling towers for jacket water, 300,000 gallons per hour	0·100	2,000
Water pumps, air compressor and reservoir for starting engines	0·075	1,500
H.T. switchboard, cables and motor generators .	0·500	10,000
Incidentals, contingencies, etc.	0·550	11,000
Total	£14·40	£288,000

house, which is illustrated diagrammatically in Figs. 124 and 125, amounts to 3·9 square feet per K.W. installed or 5·2 square feet per available K.W.

An estimate given by Mr. I. V. Robinson for the cost of a gas-driven power house equipped with ammonia recovery plant is set out in Table No. CX.

The following particulars relate to a gas power house which contains three 650 B.H.P. twin tandem engines, or a total of 1950 B.H.P., driving alternators in parallel. The capital cost was as set out in Table No. CXI.

TABLE CXI.

CAPITAL COST OF 1950 B.H.P. GAS POWER HOUSE.

Items.	Total cost. (Pre-war.)	Cost per B.H.P.
	£	£
Engine house	3,600	1·846
Engine foundations	1,200	0·615
Gas-cleaning plant for five engines	1,250	0·641
Water tank and gas holder for five engines	1,450	0·743
Three 650 B.H.P. gas engines	9,750	5·000
Electrical equipment, three generators, switchboard, cables, etc.	4,500	2·308
Erection of plant, pipework, starting compressor, travelling crane, etc.	3,400	1·744
Total	£25,150	£12·897

Table No. CXII. gives the particulars of running cost, on an annual output of 7,500,000 units, equivalent to a load factor of 65 per cent. The gas was obtained as a by-product from coke ovens and was formerly wasted. No value has therefore been given to the gas in this case.

The figures given in these two tables relate, of course, to pre-war conditions.

A few typical small power houses and substations may now be briefly described for purposes of reference.

Shipyards: Independent Power House.—A plan and elevation of the power house at the big shipyards of Messrs. Harland & Wolf, Belfast, are shown in Plate XIX. Plant to a total of 4300 K.W. is housed in a red-brick building 415 feet long by 68

feet wide, representing a ground space of 7 square feet per K.W. installed, the cubic contents being 380 cubic feet per K.W. There are five marine boilers for a working pressure of 200 lb. per square inch, each with a heating surface of 2225 square feet, and also two marine type water-tube boilers each with a heating surface of 2115 square feet. The shaft is 180 feet in height with an internal diameter of 8 feet at the cap.

TABLE CXII.

RUNNING COSTS OF 1950 B.H.P. GAS POWER HOUSE.

Items.	Total costs.	Per unit.
	£	d.
Lubricating oil	275	·0088
Waste and stores	55	·0017
Water at 5d. per 1000 galls., being the loss through evaporation in cooling towers, 2,064,000 galls.	43	·0014
Wages	819	·0262
Repairs and maintenance	250	·0080
Interest on capital, 3½ per cent.	880	·0281
Redemption Fund for Renewals—		
Gas engines, 10 per cent.	975	·0312
Generators, etc., 6 per cent.	270	·0086
Buildings, cleaning plant, gas holder, etc., 3 per cent.	285	·0091
Total	£3852	0·1231d.

The engine house shown in plan in Plate XIX. is 168 feet long by 62 feet wide and is lined throughout with glazed bricks. The roof is heavily glazed and there are also numerous wall windows. The plant comprises four Sulzer-Lahmeyer four-cylinder twin-tandem triple-expansion horizontal sets with a speed of 100 R.P.M., one having a normal output of 1000 K.W. and the other three 650 K.W. each. There are also two Allen sets with rated outputs of 350 K.W. and 150 K.W. respectively, as well as a complement of exciters, battery boosters, and motor generators. A very large Diesel set was added later in an annexe, and arrangements have more recently been made for a bulk supply from the Belfast Corporation system.

Shipyard Substation.—A typical shipyard substation containing four 250 K.W. synchronous motor-generators may be

referred to. The motors are wound for a supply at 5500 volts, and the generators are compound wound for 240 to 260 volts, each being provided with a direct-coupled starting motor of approximately 25 K.W. The floor space occupied per K.W. is 1·25 square feet, and the cubic contents 32 cubic feet per K.W. The total cost of the substation, which was constructed before the war, including buildings, plant, and high and low tension switchboards, was £6 per K.W. It may be interesting to note that the average ratio of the yearly output to input is 76 per

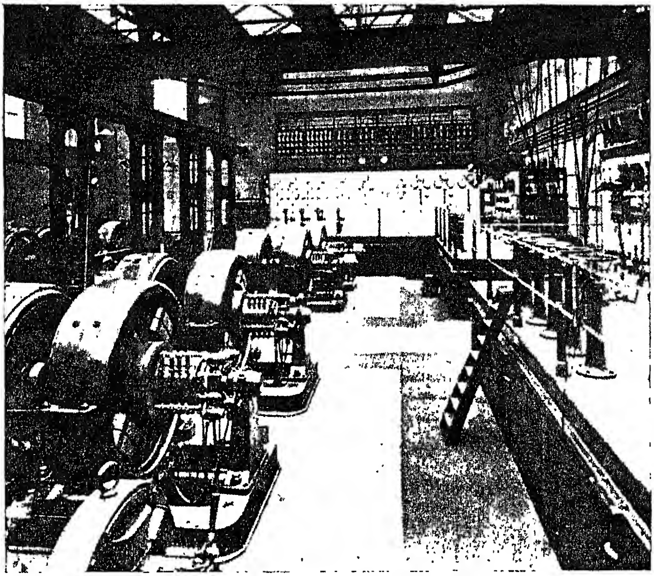


FIG. 155.

cent., the average load factor being 35 per cent., and the power factor about 0·95.

Tramways and City Substation.—Fig. 155 shows a typical substation designed for the Manchester Corporation for the tramways supply and for the general city supply. The floor space occupied is 22 square feet per K.W. and the cubic contents 80 cubic feet per K.W.

Collieries: Independent Power House.—Fig. 156 shows a plan and cross-sections of the power plant at the Cambrian

Collieries, Glamorganshire, South Wales. There are four Lancashire boilers, each 30 feet long by 9 feet diameter, for a

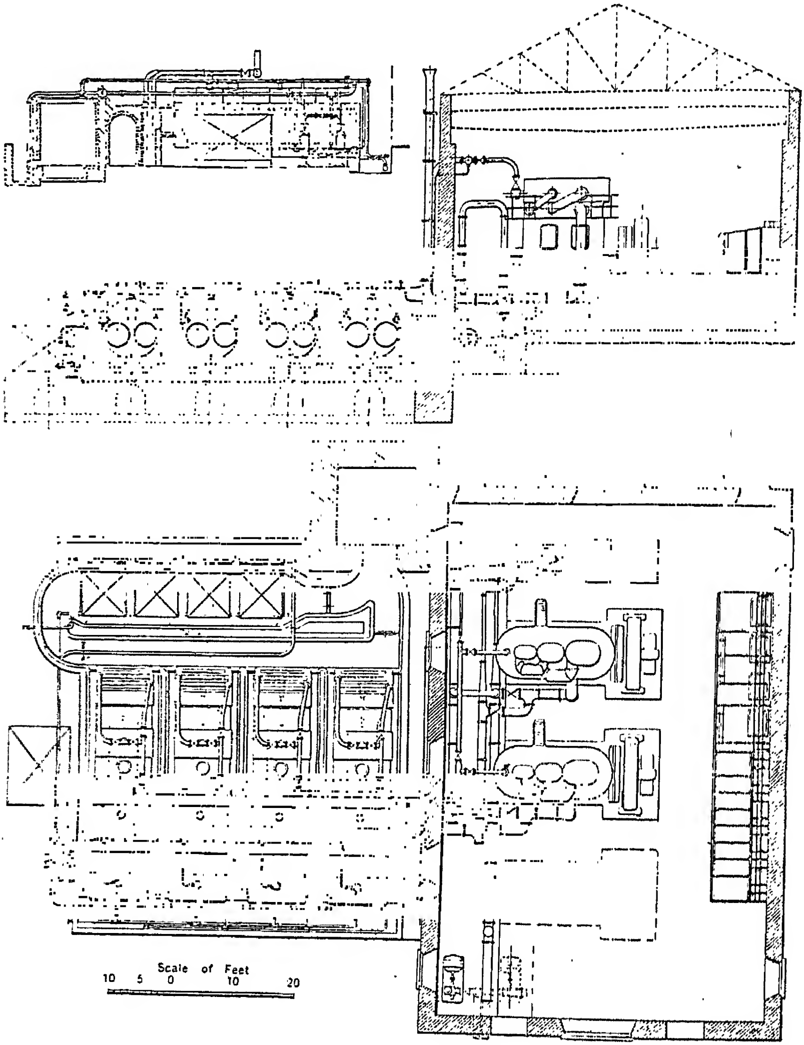


Fig. 156.

working pressure of 160 lb., and a Green's economiser; also two twin-feed pumps, each with a duty of 3000 gallons per hour.

The engine-room contains three 1000 K.V.A. Belliss-Siemens alternators (250 R.P.M., 2200 volts, 25 cycles per second) having a continuous rating of 750 K.W. at 0·75 power factor. Korting ejector condensers are provided. The floor space is 4·34 square feet per K.W. installed.

Small Rolling Mill Substation.—Fig. 157 shows a typical static substation for a small rolling mill, controlling one 500

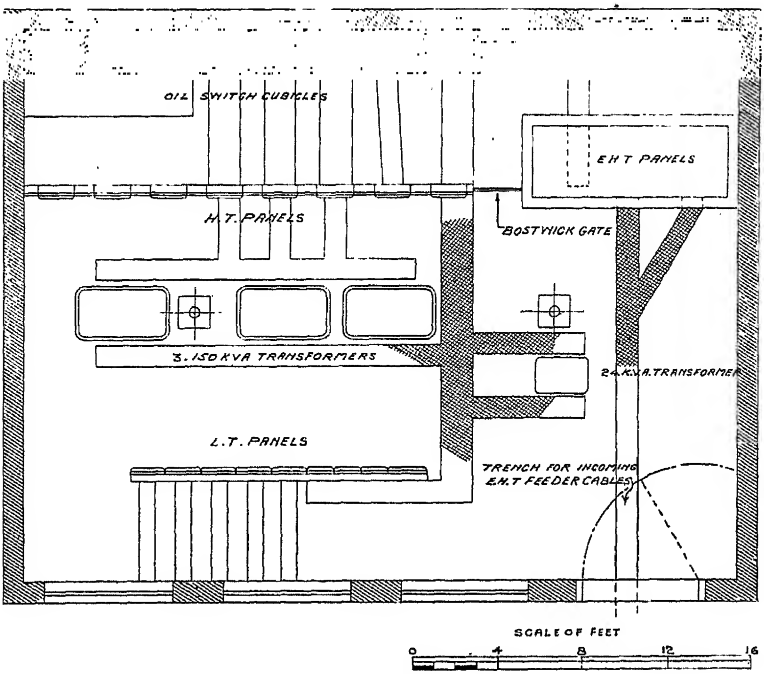


Fig. 157.

K.V.A., two 300 K.V.A., and three 150 K.V.A. static transformers, from which the three rolling mill motors, one of 400 B.H.P. and two of 250 B.H.P. as well as forty-one smaller motors ranging from 3 to 50 B.H.P. (and aggregating 672 B.H.P.) are supplied. There is a H.T. switchboard built on the wall cubicle system to control the 5500-volt feeders and primary circuits, and a low tension 3-phase board (440 volts between phases) to control the works power circuits and the lighting

circuits. Accommodation is also given to the Power Supply Authority's own board. In this case an existing building was

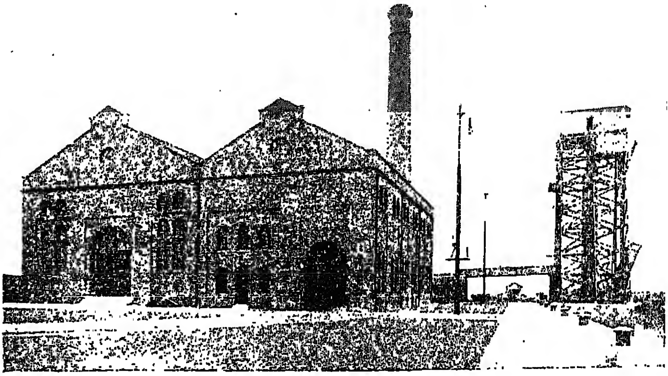


FIG. 158.

adapted as a substation with very little reconstruction, and the floor space occupied by the switchgear and three 150 K.V.A. transformers only is 1000 square feet.

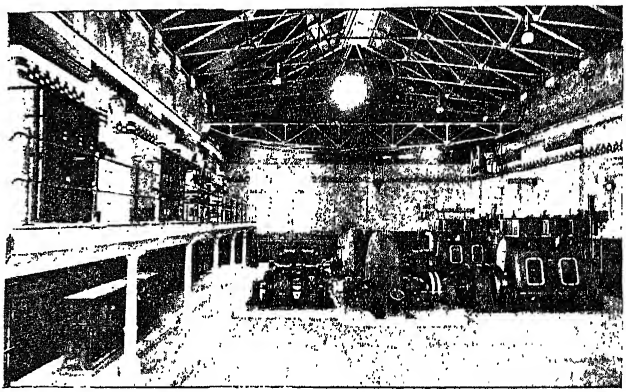


FIG. 159.

Docks: Independent Power House.—A typical direct-current dock power house, designed by Messrs. Dixon & Baxter for the Rothesay Docks, belonging to the Clyde Navigation Trustees is illustrated in Figs. 158 and 159. The plant comprises two

water-tube boilers, each evaporating 12,500 lb. per hour, and two specially arranged 250 K.W. triple-expansion steam generators as well as a third set of 120 K.W. for night loads. The steam sets are specially arranged with a very heavy fly-wheel, which, together with two coal-hoist generators, is connected to the main shaft by a special flexible coupling. Supply is given for electrically driven coal hoists, turn tables, jib cranes, capstans, and dock lighting. The output amounts to some 1,500,000 units per annum, and the maximum load on the bars to 500 K.W. The total floor space occupied (including engineer's office) is

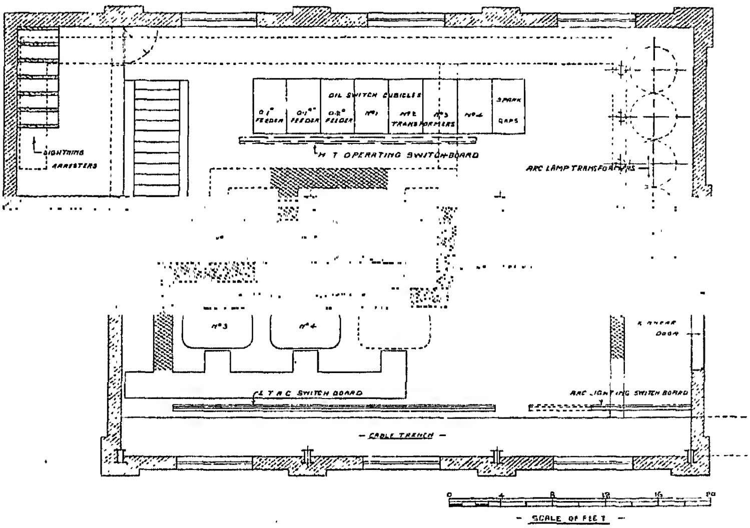


Fig. 160.

about 2·5 square feet per K.W., and the capital cost (pre-war) about £25 per K.W.

Docks Substation.—A typical 3-phase dock substation is shown in Fig. 160. This represents a substation designed by the Author for the supply of the Buenos Ayres and Pacific Railways Docks at Bahia Blanca, Argentina. It contains six 500 K.V.A. static transformers, a H.T. board to control the 5500 volt feeders and primary circuits, and also a low tension 3-phase power and lighting board. The H.T. switchgear comprises an operating panel on station floor level, and switch cubicles on the gallery floor above as shown in Fig. 161.

The switchgear provided includes—

(*a*) Three incoming feeder panels.

(*b*) Four H.T. transformer panels.

Each feeder panel is provided with the following instruments:—

(1) A loose handle with trip coil to operate the oil-break switch.

(2) Ammeter on one phase with series transformer.

(3) Three-phase reverse current relay.

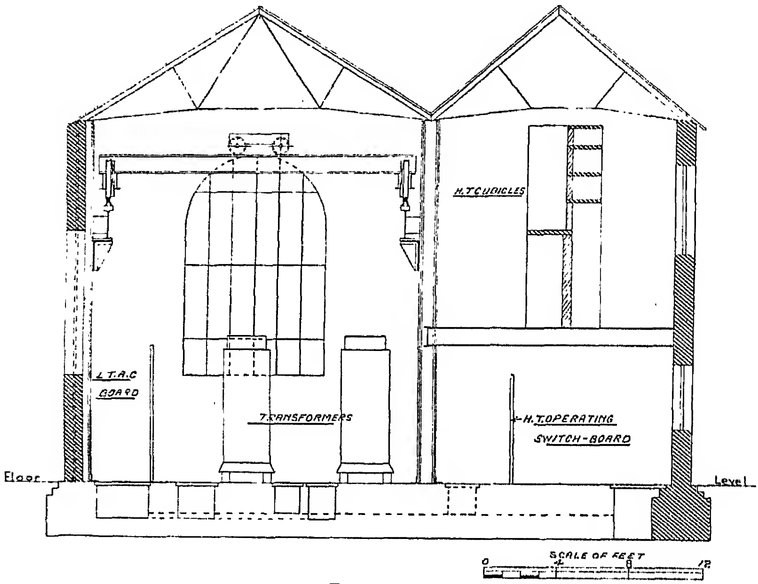


FIG. 161.

(4) Recording voltmeter (5000-8000 volts).

(5) Three isolating switches between each incoming feeder and circuit breaker (oil switch).

(6) Three isolating switches between each circuit breaker and the bus bar.

Each transformer panel is provided with—

(1) A loose handle with trip coil to operate the oil-break switch.

(2) Ammeter on one phase with series transformer.

(3) Overload time limit relay with range of current adjustment and a time limit of 5 to 30 seconds.

(4) 14-inch dial voltmeter (5000-8000 volts) with potential transformer.

(5) Three isolating switches between the oil-break transformer switch and the bus bars.

The L.T. switchboard is situated at substation level and contains 11 panels, 4 for the transformer secondaries, 6 feeder panels, and 1 arc-lighting constant-current transformer panel. The instruments provided are as follows :—

Transformer Panels (L.T.) :—

(1) One automatic oil-break switch mounted on back of the panel, with loose handle.

(2) Ammeter on one phase, with series transformer.

(3) Recording voltmeter (on one panel only).

(4) 14-inch illuminated dial voltmeter, with potential transformer.

(5) Three isolating switches between L.T. bus bars and L.T. oil-immersed switch.

(6) Power-factor indicator.

Feeder Panels (L.T.) :—

(1) Automatic oil-break switch with loose handle.

(2) Three ammeters, one on each phase, complete with series transformers.

(3) Three isolating switches between L.T. bus bars and oil-break switch.

(4) Three-phase integrating watt-hour meter.

Arc-lighting Panel :—

(1) Three automatic single-phase oil-break switches mounted on back of panel with loose handles, and each provided with trip coils and series transformers.

(2) Three ammeters, one on each phase, and provided with series transformers.

(3) Three single-phase watt-hour meters, with instrument transformer.

There is a five-ton overhead crane.

The building is a steel skeleton structure with brick fillings and eternit sheet roofing. The floor space occupied is 0·6

square foot per K.V.A. installed, and the cubic contents 15·6 cubic feet per K.V.A. The cost (pre-war) complete with equipment was £3·08 per K.V.A., of which the buildings represented £1·29.

Power is supplied from this substation to jib cranes, traversers, turn-tables, capstans, and a very large electrically operated grain elevator and 20,000-ton silo containing 34 motors aggregating 955 B.H.P.

Railway and Tramway Substations.—Fig. 162 shows a typical 3000 K.W. railway substation on the Liverpool and Southport Railway containing rotary converters, each of 600 K.W., with transformers of the air-blast type (three single-phase to each converter). The ventilation is provided by two induction motor-driven blowers, each of 5 H.P., coupled direct to a fan displacing 8000 cubic feet per minute at a pressure of 3 inches. The floor space occupied per K.W. is 1·33 square feet, and the total cubical contents 40 cubic feet per K.W. The total cost of the substation, including building, plant and switchgear, was £6·8 per K.W. installed, this, of course, being a pre-war figure.

Fig. 163 shows a plan of a typical traction substation as designed for the L.C.C. tramways. In this substation both synchronous and induction motor generators are installed. The motors are 3-phase star connected, the supply being at a pressure of 6600 volts between phases, and at a frequency of 25 ∼ per second. The generator fields are all shunt wound, and not compounded, in order to simplify the switchgear. The synchronous sets are excited at 125 volts from a direct-current generator mounted on the main shaft. The induction sets have short-circuited rotors, being started up on the direct-current side and switched directly on to the H.T. bus bars at synchronous speed, which is indicated to the attendant by a small enamelled iron disc screwed to the end of the generator shaft and painted with alternate black and white sectors. The sectors, illuminated by a 25 ∼ lamp, appear to be stationary when at synchronous speed. A sectional view of the H.T. switchgear was shown in Fig. 132.

The pre-war cost of a 3000 K.W. substation (of the same

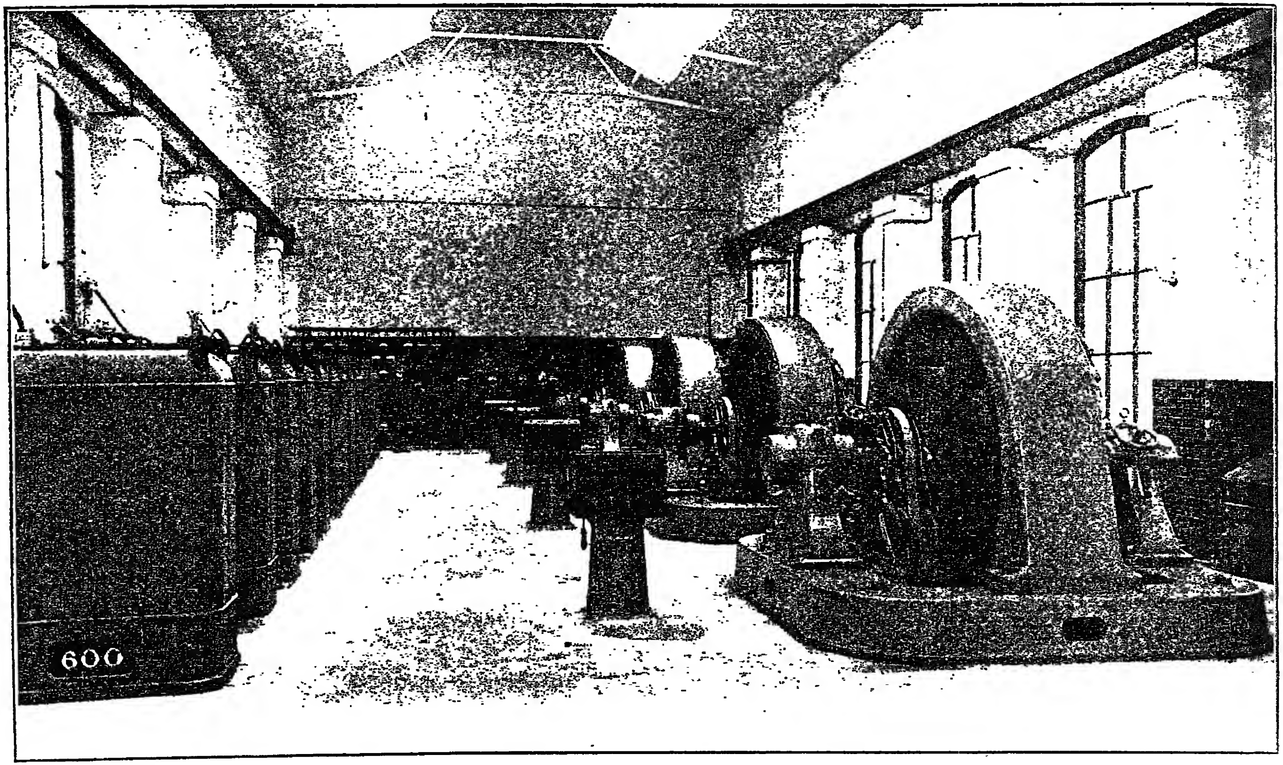


FIG. 162.

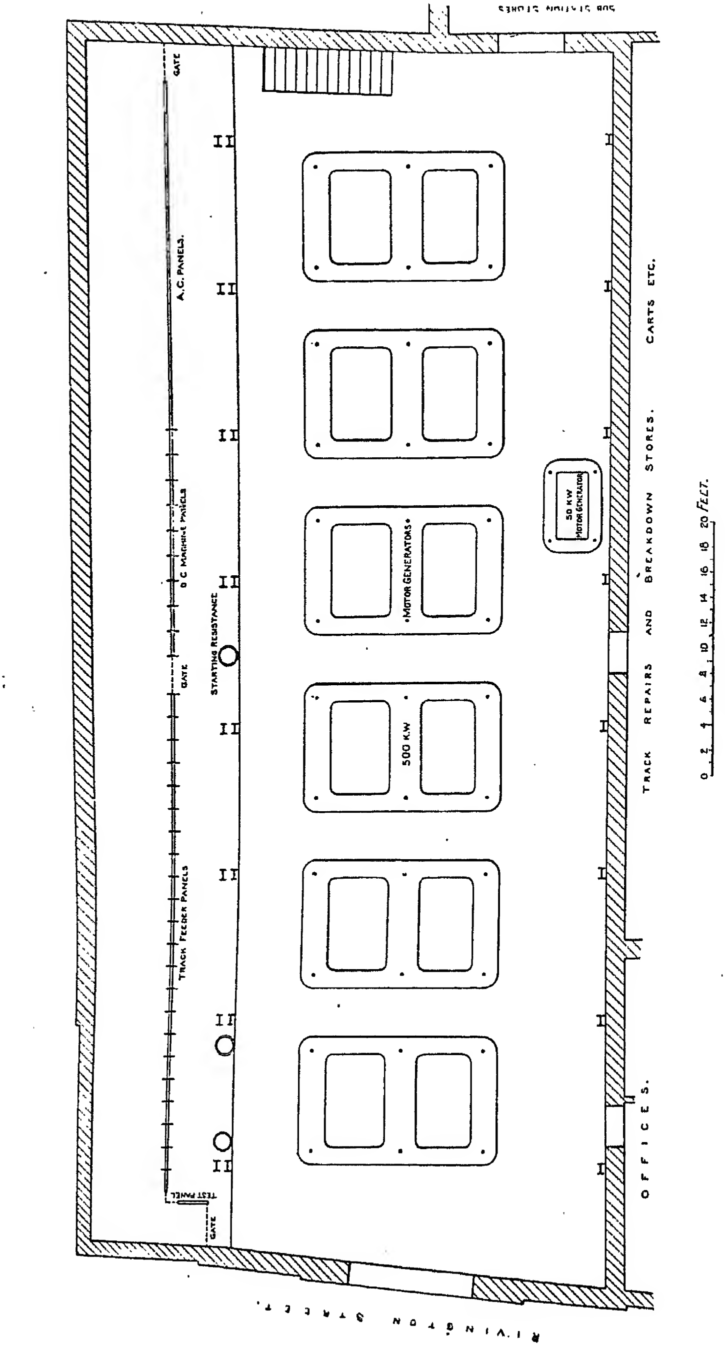

SUB STATION STORES
GATE
A.C. PANELS
D.C. MACHINE PANELS
GATE
STARTING RESISTANCE
TRACK FEEDER PANELS
TEST PANEL
GATE
MOTOR GENERATORS
500 K.W
50 KW MOTOR GENERATOR
TRACK REPAIRS AND BREAKDOWN STORES. CARTS ETC.
OFFICES.
RIVINGTON STREET.
0 2 4 6 8 10 12 14 16 18 20 FEET.

FIG. 163.

type as illustrated in Fig. 163), exclusive of the cost of site, is given by Mr. Rider as shown in Table No. CXIII.

TABLE CXIII.

3000 K.W. SUBSTATION: PRE-WAR COST.

Items.	Total cost.	Cost per kilowatt.
	£	£
Motor generators	0,400	3·47
H. and L.T. switchgear	3,420	1·14
Crane, tools, lighting, etc.	400	0·13
Buildings	6,520	2·17
Total	£20,720	£6·91

The diversity factor of the 23 substations supplying the L.C.C. tramway system, that is, the ratio of the sum of the maximum loads on the separate substations to the observed simultaneous maximum load at the power house, is 1·25.

The annual efficiency of these substations, i.e. the ratio of units output to units input, is 73·5 per cent. for the synchronous sets, and 82·1 per cent. for the induction motor generator substations.

Combined 3-phase 4-wire Transformer and Rotary Substation.—Another typical substation is shown in Fig. 164. This was constructed to the Author's specifications both for the general supply of a town in South America by a 3-phase 4-wire system, and also for a 500-600 volt traction supply through rotaries. The building is of steel framework with brick panels, and the roofing and ceiling beams of eternit sheets. The general supply is from 3-phase 500 K.V.A. transformers supplied at a pressure of 6600 volts (50 ∽), with a secondary pressure of 380 volts between phases, and 220 volts between each phase and the neutral.

The street arc lighting is from single-phase constant-current self-regulating transformers.

The traction supply is from four 350 K.W. rotaries, each complete with its own transformer and exciter.

There are three switchboards, all the H.T. work being concentrated on the gallery in cubicles, in a manner similar to that shown in Fig. 132. All the operating boards, viz. (*a*) the

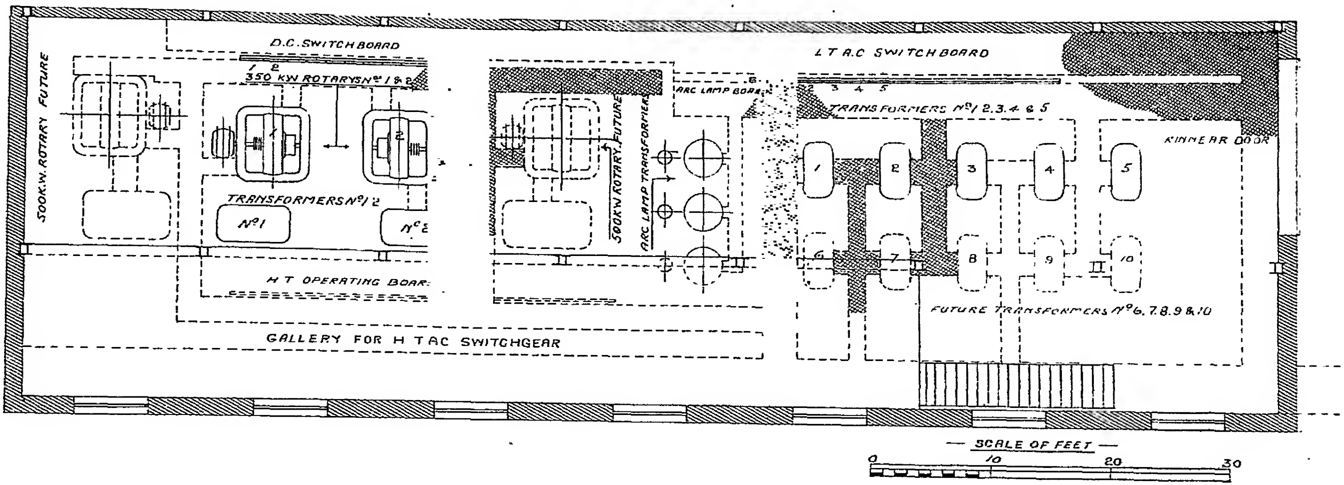

D.C. SWITCH BOARD
350 KW ROTARYS Nº 1 & 2
500K.W. ROTARY FUTURE
TRANSFORMERS Nº 1 2
Nº 1
Nº 2
H T OPERATING BOAR
500K.W. ROTARY. FUTURE
ARC LAMP TRANSFORMERS
ARC LAMP BOARD
L T A.C SWITCH BOARD
TRANSFORMERS Nº 1 2.3.4 & 5
KINNEAR DOOR
FUTURE TRANSFORMERS Nº 6.7.8.9 & 10
GALLERY FOR H T AC SWITCHGEAR
SCALE OF FEET
0
10
20
30

FIG. 164.

H.T. operating panels, (*b*) the L.T.A.C. board, and (*c*) the traction 550 volt board, are on the machine floor level.

The pre-war cost of this substation erected abroad and excluding the site value was as shown in Table No. CXIV., the total capacity being 2650 K.W. (the transformers being taken at an average power factor of 0·85).

TABLE CXIV.

SUBSTATION ERECTED ABROAD: PRE-WAR COST.

Items.	Total capital cost.	Per K.W. of plant.	Cost per total K.W. installed.
	£	£	£
Buildings	2708		1·02
H.T. and L.T. switchgear and connecting cables	4878		1·84
5 transformers, 1250 K.W.	955	0·76	1·87
4 rotaries with transformers, 1400 K.W.	4007	2·86	
Crane, tools, lighting, etc.	352		0·13
Total	£12,900		£4·86

In concluding these notes on small power houses and substations, it may again be stated that it will be found cheaper in some cases to install a small independent power house, and in others to purchase power in bulk from an outside authority. It is largely a matter of relative cost, though the bulk supply alternative has this further recommendation, viz. that the supply is always available and may be switched on when required or switched off if the works are closed. Space—often of great value in older works—is also saved. The present-day tendency is for the managers of works to avail themselves of an outside supply where that is available. Still, there are cases, such as collieries, where the small coal is often of insufficient commercial value to outsiders; other kinds of works with exhaust steam or waste gases; or works obliged to raise steam for other purposes, and so forth, where an independent power house is certainly of greater economy to the factory. As the Author has insisted throughout this book, every case must be looked into on its merits. It should be possible, by reference to the various chapters herein, for any engineer to be able to find within reasonably accurate limits, (*a*) the first cost, and (*b*)

such information as will (combined with his own local knowledge of the cost of coal, oil, or gas, as the case may be, and the cost of labour) enable him to determine the probable cost of generation.

Losses in Conversion of Heat Energy of Coal.—From the point of view of fuel economy, the process of converting the heat energy of coal into electrical energy even by the most modern types of steam or gas-driven power plant is undoubtedly a wasteful one.

The following Table No. CXV. is based upon an analysis given by H. G. Stott (Trans. Amer. Inst. of Electrical Engineers, 1906) of the average thermal losses in the operation of an efficient steam power station during a year's working.

TABLE CXV.

STEAM POWER STATION: THERMAL BALANCE SHEET.

Items.	B.Th.U.	Per cent.
Calorific value of coal: per lb.	14,150	100
Debit:		
Rejected to condenser	8524	60·1
Loss in stack	3212	22·7
Loss in boiler radiation and leakage	1131	8·0
Loss in ashes	340	2·4
Delivered to circulator	223	1·6
Delivered to feed pumps	203	1·4
Loss in leakage and high-pressure drips	152	1·1
Engine friction	111	0·8
Delivered to small auxiliaries	51	0·4
Electrical losses	36	0·3
Heating	31	0·2
Other power house auxiliaries	29	0·2
Loss in pipe radiation	28	0·2
Engine radiation losses	28	0·2
Total	14,099	99·6
Credit:		
Returned by economiser	960	6·8
Returned by feed-water heaters	441	3·1
Total	1401	9·9
Nett losses	12,698	89·7
Balance:		
Delivered as electrical energy to bus bars	1452	10·3

From the above figures it is seen that a very large proportion of the total heat units in the coal is rejected to the condenser and lost in the products of combustion. The important part played by economisers and feed water heaters in the general thermal economy of a steam power station is also apparent.

The statistics given in Table No. CXVI. relate to power stations in the United Kingdom which generated electricity by means of steam, and are taken from a published statement of the Technical Adviser to the Coal Mines Department.

TABLE CXVI.

STEAM POWER STATIONS IN UNITED KINGDOM.

(Year ending March 31, 1918.)

Number of stations to which statistics apply.	Total units generated.	Coal consumption.		Average thermal efficiency.*
		Total.	Average per unit generated.	
		tons.	lbs	per cent.
421	4,674,353,328	7,249,981	3·47	8·5
40 (selected) .	2,276,606,974 †	2,616,912	2·57	11·5
381 (remainder) .	2,398,746,354 †	4,633,069	4·32	6·8
7 (of selected 40)	1,299,128,412	1,421,858	2·45	12·1

* It was assumed that 11,500 B.Th.U. per lb. represented a fair average calorific value for the fuel supplied to all the stations throughout the country.

† Totals as given in published statement.

Upon the basis of the assumed calorific value for the coal consumed, the highest recorded thermal efficiency among the stations dealt with in the above table was just over 13 per cent. It must be noted, however, that the coal available to power stations in 1917-18, as to all other consumers, was inferior in quality to that supplied before the war and contained a large amount of ash. The Author is acquainted with cases where the fuel supplied had a calorific value of less than 10,000 B.Th.U. per lb., and it is not improbable that the average value for the

power stations throughout the country was somewhat less than the assumed value of 11,500 B.Th.U. per lb. as fired.

Better results have of course been obtained with modern steam power plant; figures for a full year's working of the power station at Connors Creek, U.S.A., show a fuel consumption averaging about 20,000 B.Th.U. per unit generated, and representing a thermal efficiency of about 18 per cent. Similar results have been obtained at the Dunston station of the Newcastle-on-Tyne Electric Power Supply Company, England.

Dealing next with gas engine power houses, the average losses in the conversion of the heat energy of coal into electrical energy by means of gas producer and gas engine electric plant working at rated load are as set out in Table No. CXVII.

TABLE CXVII.

GAS ENGINE POWER PLANT: THERMAL BALANCE SHEET.

Items.	B.Th.U.		Per cent.	
Calorific value of coal: per lb.		12,500		100
Losses:				
In producer and auxiliaries	2,500		20	
In cooling water for cylinder jackets	2,375		19	
In exhaust gases	3,750		30	
In engine friction	813		6·5	
In generator	62		0·5	
Total losses		9,500		76·0
Balance: Converted into electrical energy		3,000		24·0

With regard to these figures, it is to be observed that the thermal efficiency of the gas producer plant, including auxiliaries, is taken at the high value of 80 per cent., and that no allowance has been made for the steam-raising value of the waste heat rejected in the exhaust gases.

At rated load and on trial runs, thermal efficiencies as high as 24 per cent. may be obtained with gas engine electric plant. In actual service on average commercial load factors, however, the thermal efficiency may be taken at about one-half this figure.

A comparison may be made between the average thermal efficiencies of modern steam and gas driven plant as follows, assuming the employment of coal having a calorific value of 12,000 B.Th.U. per lb. in each case.

(*a*) *Steam plant.*—With a boiler evaporating, on an average, 7·5 lb. of water per lb. of coal, a ton of coal will yield 16,800 lb. of steam. A modern steam turbine requires 8·2 lb. of steam per B.H.P. hour, so that a ton of coal will produce 2048 B.H.P. hours.

(*b*) *Gas engine plant.*—With a gas producer operating, on an average, at a thermal efficiency of 75 per cent., a ton of coal of the assumed calorific value will yield 20,160,000 B.Th.U. in the form of power gas. A modern gas engine requires 9500 B.Th.U. or less per B.H.P. hour, so that a ton of coal will produce 2122 B.H.P. hours.

It may be well to point out that comparisons based upon thermal efficiencies alone are apt to be misleading. There are other important factors which must be considered by the designer when deciding between steam and gas-driven plant, as has been emphasized in previous chapters.

Combined Gas and Steam Power Houses.—An economy in fuel consumption can be effected by adopting a combination of gas engine and steam-driven plant, and there is a good deal to be said for such a combination for small and medium sized power houses for isolated towns. It is, of course, more applicable to power houses running on the lower annual load factors, but furnishes an effective running combination in that the gas plant can take care of the higher plant load factors, with consequent economies in coal consumption, and the steam plant of the peak loads.

With such a combination of plant, it may prove profitable to install ammonia recovery producers in connection with the gas engine section. As previously stated, however, the relative economy will depend upon the size of the installation, the cost of coal and of labour, the load factor on the whole plant, and especially upon the revenue obtainable from the sale of ammonium sulphate. All these points require the closest investigation.

Estimates were prepared by Messrs. Andrews & Porter ("Journal, Institution of Electrical Engineers," 1909) of the relative costs of gas, steam, and combined gas and steam power houses having a capacity of 4000 K.W. and annual load factors of 10, 15, and 24 per cent. In arriving at the running costs of

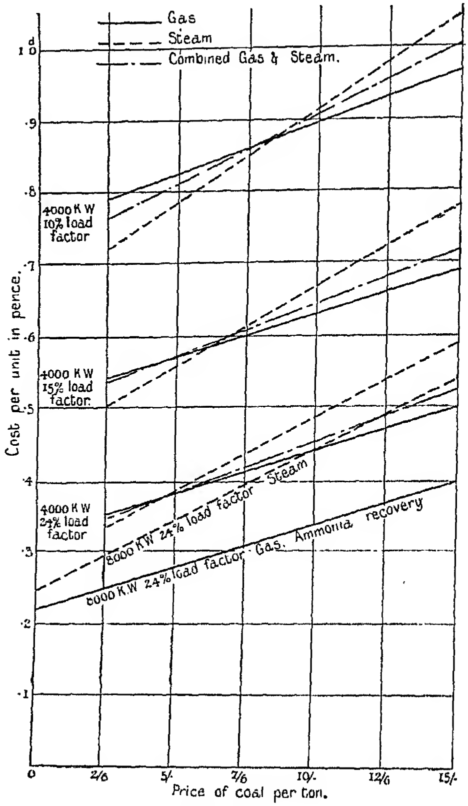


FIG. 165.

the combined plant, no credit was taken for the recovery of ammonium sulphate.

The curves given in Fig. 165 show the effect of variations in the price of coal upon the estimated running costs of the three types of installation.

It will be observed that with coal above a certain price,

depending on the load factor, the gas-engine power house shows to increasing advantage as the price of coal continues to rise. As would be expected, the combined installation stands between the other two as regards relative economy.

Power Generation with By-Product Recovery.—It has often been urged, on the grounds of economy, that the practice of burning raw coal for the generation of power should give way to systems whereby the potential by-products from the coal are first recovered and the resulting fuel products utilized for power purposes.

Such systems have already been in successful operation on a small or moderate scale, and reference was made in a previous chapter to the use of ammonia recovery producers at gas engine power houses. The extension of by-product recovery practice to power generation on a large scale has had many advocates, and at first sight presents several attractions. The problem, however, is one of much complexity, and in a number of cases the economies claimed to be obtainable are based upon an insufficient consideration of all the factors.

It is important at the outset to point out that the adoption of by-product recovery at large power houses would not lead to any economy in fuel consumption. In such power houses, the use of gas engines as at present developed would be impracticable, and modern steam turbine plant would have to be adopted. While certain economies would result from the development of high efficiency gas-fired boilers, against these there must be set the thermal losses necessarily incurred in treating coal for by-product recovery and at the same time converting it into other fuel products such as coke or power gas, or both. These losses range from 25 to 50 per cent. and over according to the process adopted, and more than counterbalance any probable improvement in boiler efficiency. The nett result is therefore an increase in the consumption of coal per unit generated as compared with an equivalent coal-fired power station. In the case of a power house equipped with ammonia recovery producers for gasifying the whole of the coal, the total coal consumption would be from 70 to 80 per cent. greater than that of a corresponding coal-fired station.

From the above observations, it is apparent that the cost of coal will have a considerable influence upon the financial aspects of by-product recovery power schemes. In this connection, reference may be made to Fig. 166 which indicates the price at which thermal units in the form of gaseous fuel would have to be delivered at a power house to compete on an equality with coal at different prices per ton, assuming the same thermal efficiency for gas-firing as for coal-fired boilers.

The bearing of Fig. 166 may be illustrated by contrasting the position of two power houses, one fitted for coal firing and

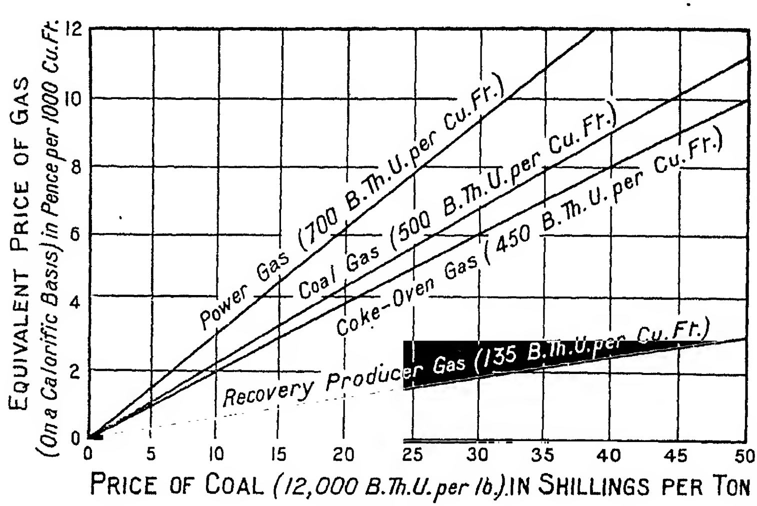


FIG. 166.

the other provided with recovery producer plant for gasifying the whole of the fuel employed. Apart from the running costs of the power plant (exclusive of fuel), which would be approximately the same in each instance, account has to be taken in the second case of the following items, namely: (*a*) the cost of the increased quantity of coal required for a given output of electrical energy; (*b*) the costs of gasification; (*c*) the costs of by-product recovery; (*d*) the capital charges on the recovery producer installation; and (*e*) the revenue obtainable from the sale of the by-products, sulphate of ammonia and tar. With coal for direct-firing at, say, 30s. per ton, it is seen from Fig.

166 that the by-product recovery system would not result in cheaper electrical energy unless the nett effect of items (*a*) to (*e*) permitted the delivery of producer gas to the power plant at a cost less than 1·8d. per 1000 cubic feet. It must also be remembered that whereas the costs of coal and of labour are the principal variables in the case of direct firing, the by-product recovery system includes a further fluctuating factor, namely, the market price of the by-products.

In the course of an enquiry undertaken by the Nitrogen Products Committee of the British Ministry of Munitions during the years 1916-1919, the Power Sub-Committee (of which the Author was Chairman) made a very full investigation of the possibility of applying various by-product recovery processes to power generation on a large scale. The principal object of the investigation was to ascertain whether the use of such processes, resulting in the conservation of valuable nitrogenous and other by-products which are entirely lost by burning raw coal under boilers, would bring about a sufficient reduction in the cost of electrical energy to permit of the operation, in Great Britain, of processes for the fixation of atmospheric nitrogen hitherto confined to countries where cheap water power is available. The problem was simplified by reason of the fact that the requirements for the economical operation of certain nitrogen fixation processes, namely, a large supply of power at a high annual load factor approximating to 100 per cent., represent the essential conditions for the generation of electrical energy at the lowest possible cost.

Most of the information available to the Committee represented the outcome of first-hand practical experience; in cases, however, where there was no established commercial practice extending over an adequate period, use had to be made of estimated results still requiring to be fully substantiated.

The conclusions arrived at by the Committee in 1918 are fully set out in their Final Report (Cmd. 482, 1920) and are of an adverse character. A summary of the salient points disclosed by the investigation may be given in view of the importance of the subject and of the extravagant claims that have sometimes been advanced.

The general financial relationship of direct coal-firing and by-product recovery power schemes is illustrated by the chart in Fig. 167, compiled from the individual charts given in the

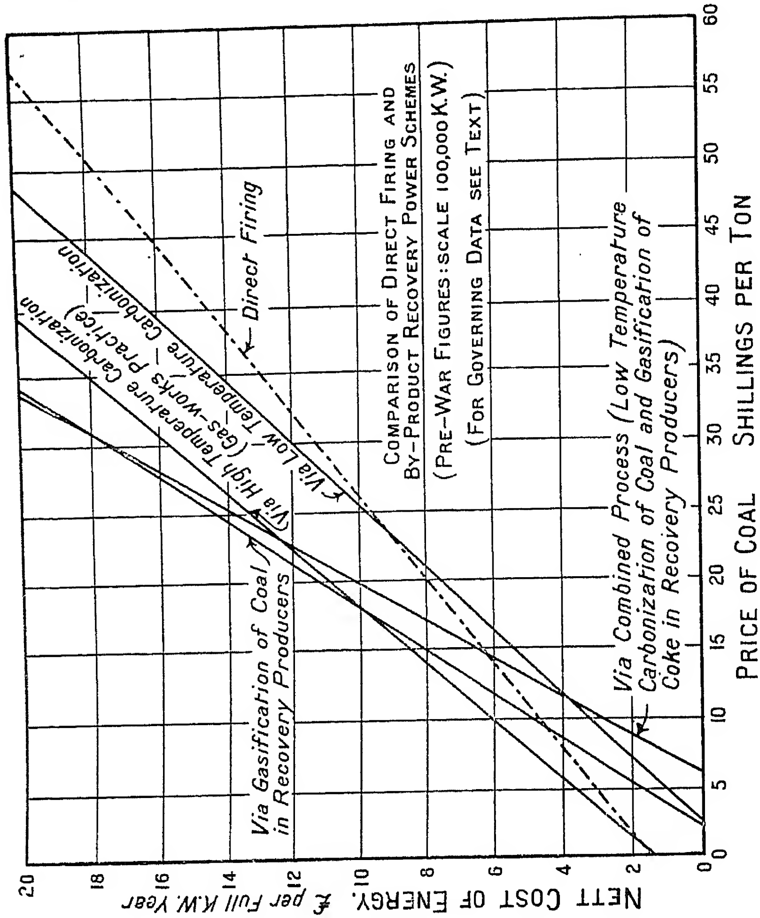


Fig. 167.

above-mentioned report. The whole of the results are governed by the following considerations and factors :—

(*a*) All capital and operating costs are based on *pre-war* conditions.

(*b*) Scale of steam turbo-electric power installation in each case taken at 100,000 K.W. maximum load.

(*c*) Annual load factor taken at 100 per cent.

(*d*) Calorific value of coal as fired taken at 12,000 B.Th.U. per lb. in all cases.

(*e*) Thermal efficiencies of boilers with economisers and superheaters taken as follows: 80 per cent. when fired with coal or low temperature coke (smokeless fuel), and 75 per cent. when fired with gas coke or power gas.

(*f*) All surplus fuel products (coke, or gas, or both) resulting from the treatment of the coal under by-product recovery conditions are utilized for firing the boilers of the power station.

(*g*) The *nett* revenues (i.e. market price less cost of manufacture) from the sale of by-products taken as follows: sulphate of ammonia, £10 per ton; benzol, toluol, and light spirit, 8d. per gallon; gas works tar, 2d. per gallon; tar from low temperature carbonization of coal, 3d. per gallon; and tar from recovery producer plant, 12s. 6d. per ton.

Further information bearing upon the curves illustrated in Fig. 167 is set out in Table No. CXVIII. on the next page, compiled from data given in the report. The table indicates the relative thermal efficiencies, capital costs, running costs, capital charges, and coal consumption of direct firing and by-product recovery power schemes. It also indicates the effect upon the cost of energy of fluctuations in the revenue obtainable from the sale of the various by-products, and the costs that must be recouped by such sales to place the by-product power schemes merely on an equality with direct coal-firing.

Comparing the different by-product schemes with coal-firing, it will be seen that the former involve:—

(*a*) An increase in the coal consumption per K.W. year ranging from 32 to 120 per cent.

(*b*) An increase in the total capital outlay per K.W. of maximum load ranging from 66 to 180 per cent.

(*c*) An increase in the running costs per K.W. year (excluding coal and capital charges) ranging from 218 to 665 per cent.

With very cheap coal and a reasonably good return from the sale of by-products, some of the by-product schemes show an advantage over direct-firing, as indicated by the curves in Fig. 167. In view, however, of the fact that a given variation

TABLE CXVIII.

COMPARISON OF DIRECT COAL-FIRING AND BY-PRODUCT POWER SCHEMES.

(See governing considerations and factors on p. 438.)

Items.	Direct coal-firing.	via High temperature carbonization (gas-works practice).	via Low temperature carbonization (based on claims made).	via Complete gasification of coal in recovery producers.	via Low temperature carbonization of coal followed by complete gasification of resulting coke in recovery producers (based on claims made).
Thermal efficiency of carbonization or gasification (per cent.)	—	73·7	76·2	56·3	48·5
Comparative overall thermal efficiency of power scheme (per cent.) (coal firing = 100) .	100	69·1	75·6	52·5	45·5
Ratio of coal consumption to that of a direct coal-fired station .	1	1·45	1·32	1·90	2·2
Capital cost of complete power installation per K.W. of maximum load . . . . (£)	10·26	20·63	17·04	19·20	28·79
Ratio of capital cost to that of a direct coal-fired station . .	1	2·01	1·66	1·87	2·81
Running costs (ex coal and capital charges) per full K.W. year . . . . . (£)	0·54	2·18	1·72	2·54	4·13
Ratio of running costs (ex coal and capital charges) to that of a direct coal-fired station .	1	4·04	3·18	4·70	7·65
Capital charges per full K.W. year. . . . . . (£)	0·91	1·95	1·59	1·80	2·76
Ratio of capital charges to that of a direct coal-fired station .	1	2·14	1·75	1·98	3·03
Coal consumption per full K.W. year (tons)	6·5	9·4	8·6	12·3	14·3
Effect upon cost of energy per full K.W. year of variation of 1s. per ton in price of coal (£)	0·325	0·47	0·43	0·615	0·715
Effect upon cost of energy per full K.W. year of variations in *nett* revenue from by-products as under :—					
(*a*) Ammonium sulphate (variation £1 per ton) . . (£)	—	0·10	0·11	0·52	0·59
(*b*) Benzol, toluol or light spirit (variation 1d. per gallon) (£)	—	0·12	0·16	—	0·27
(*c*) Tar (variation 1d. per gallon) . . . . . (£)	—	0·39	0·64	0·56	1·07
Nett revenue necessary per full K.W. year to place by-product power scheme on an *equality* with direct coal-firing; i.e. to equate out the running costs and capital charges of carbonization or gasification plant and also the cost of the extra coal consumed.	—	£2·68 plus revenue equal to cost of 2·9 tons of coal.	£1·86 plus revenue equal to cost of 2·1 tons of coal.	£2·89 plus revenue equal to cost of 5·8 tons of coal.	£5·44 plus revenue equal to cost of 7·8 tons of coal.

in the price of coal has a greater effect upon such schemes than upon direct-firing, it follows that whatever may be the value of the by-products recovered, there is a limiting price of coal for each scheme beyond which direct-firing is the cheaper for the generation of power. The greater the value of the by-products however, the higher is this limiting price of coal for a given scheme.

In any case where a by-product scheme shows to advantage as compared with direct-firing, it is obvious that a sustained market price for by-products is an essential factor in providing a margin in the cost of generation. The effect of fluctuations in the market price is shown in Table No. CXVIII., and it will be seen that in the two schemes which give the highest yield of by-products (and also consume the largest quantities of coal), namely, the one-stage and two-stage gasification schemes, the price of ammonium sulphate is an important factor in the general financial results. As by-product power schemes would be confronted with fluctuations not only in the cost of coal and in rates for labour but also in the market price of by-products, it is clear that their financial stability over a period of years would be much less certain than that of direct-firing.

Even when other conditions are favourable, high prices for coal and high rates of wages are a severe handicap to by-product power schemes, as will be apparent from Fig. 167 and Table No. CXVIII. The bearing of these factors upon the future prospects of such schemes was emphasized by the Nitrogen Products Committee, and in concluding their observations (in 1918-19) they pointed out that:—

"It must be recognized, however, that a time might come when the price of coal and further developments in the manufacture of various chemical products by synthetic methods would render it altogether uneconomical to apply by-product recovery processes to the production of power. In this event, it would clearly be unjustifiable, even as a national measure, to sacrifice the advantages of direct coal-firing for the purpose of conserving products that could be obtained more economically by other methods."

As an example of the effect of changed economic conditions,

consideration may be given to the figures quoted by the Committee in connection with the application of a well-established commercial process, such as recovery producer practice, to power generation on a large scale. It is shown in the report of the Committee that under pre-war conditions and with nett revenues of 12s. 6d. per ton for producer tar and £10 per ton for ammonium sulphate (fair average values in Great Britain), the maximum price of coal at which the gasification power scheme could have competed on an equality with direct-firing (with coal at the same price) was somewhat less than 9s. 6d. per ton. Assume now an advance of 100 per cent. in all pre-war costs and prices for plant, materials, wages, etc., and also that coal either for by-product recovery purposes or for direct firing could not be purchased for less than 30s. per ton ; further, assume that the producer tar would have double its original value under such conditions. Making corresponding adjustments in the figures for direct-firing and for recovery producer practice given in the report, it can be shown that with coal at 30s. per ton in both cases, a *nett* revenue of as much as £26 per ton for ammonium sulphate would have to be obtained merely to place the by-product power scheme on an equality with direct-firing.

There is no question that the factors adverse to the financial stability or success of by-product power schemes are of a much more serious character under the prevailing economic conditions of this country than they were before the war, and even then such schemes, when considered critically, could not be regarded as offering any strong inducements to private enterprise. As far as well-tried commercial processes are concerned, their employment *merely* for the purposes of providing fuel products for power generation on a large scale and of conserving by-products would be commercially unjustifiable under existing conditions.

One aspect of the general problem, which was not dealt with by the Nitrogen Products Committee, demands a brief notice, namely, the generation of power as an auxiliary to low temperature carbonization, the low temperature process being *primarily* utilized for the manufacture of a smokeless domestic fuel with by-product recovery, and the surplus gas from the

process being employed for power generation. The financial economy of such a scheme from the point of view of electricity supply would depend upon the price at which the surplus power gas could be delivered to the power house and the relation of this price to the cost of coal at an equivalent direct-fired station. The price of the surplus gas would depend, on the one hand, upon the working expenses and capital charges for the carbonizing plant and the cost of the coal treated, and on the other hand upon the yield of smokeless fuel, by-products, and surplus gas, and upon the nett revenue obtainable from the sale of the fuel and by-products. Some indication of the financial possibilities can be obtained by a study of the figures given by the Nitrogen Products Committee and based on the claims made for low temperature carbonization. Whatever may be the hopes in this direction, however, the claims made in respect of capital and running costs and of average yields of smokeless fuel, by-products and power gas have not yet been satisfactorily established by large-scale commercial operations carried on for an adequate period. Until this has been done, and an assured market created for smokeless fuel at a selling price which will show an adequate profit, the future prospects of low temperature carbonization as an auxiliary to power generation must obviously remain a matter of speculation only.

Even if the low temperature process is ultimately proved to have a sound commercial basis, there are other considerations besides finance which will certainly affect the extent to which the process could be utilized for power generation. For example, the magnitude of the constructional work involved in adapting by-product recovery processes for the purpose in question becomes a matter of very serious moment, as is clearly indicated by the data embodied in the report of the Nitrogen Products Committee to which the reader may be referred. With regard to a low temperature carbonization and power scheme of the kind considered above, it can be shown from figures in the report that after allowing for thermal losses and plant requirements, it would be necessary to carbonize 11 tons of coal (yielding 7·7 tons of smokeless fuel) in order to obtain surplus power gas equivalent thermally to one ton of coal.

A large modern coal-fired power house having an annual load factor of say 40 per cent. and a maximum demand of 50,000 K.W. would consume about 250,000 tons of coal per annum, or approximately 700 tons per day. For an equivalent power house depending entirely upon surplus gas from a carbonizing plant manufacturing smokeless fuel for sale, the quantity of coal required to be supplied and treated would amount to not less than 2,750,000 tons per annum, or between 7000 and 8000 tons per diem. Moreover, the quantity of smokeless fuel to be handled and disposed of would amount to over 2,000,000 tons per annum, or between 5000 and 6000 tons per day. From the point of view of power house design, the significance of such figures will be better appreciated when it is pointed out that at the largest individual carbonizing works in the world, namely, the Beckton gasworks near London, about 5000 tons of coal are consumed per day during the period of maximum demand in the winter, about 3000 tons of gas coke being obtained.

The critical investigations of the Nitrogen Products Committee when reviewed in the light of prevailing economic conditions lead definitely to the conclusion that the prospects of obtaining, through the medium of by-product recovery processes, *large supplies* of electrical energy at a lower cost than by direct coal-firing are practically negligible notwithstanding the claims made to the contrary. Even in the case of a process for which commercial success was reasonably certain, the financial inducements would have to be very strong indeed for capital to be forthcoming for undertakings of the magnitude indicated. Apart from financial considerations, the enormous scale of the engineering works and coal requirements even for a single large power house only, would obviously render the application of by-product recovery processes to power generation a very gradual development. Moreover, the latter factors would probably debar any appreciable proportion of the electrical output of Great Britain from ever being generated under by-product recovery conditions.

Utilization of Waste Heat.—Owing to the increasing attention devoted to the question of fuel conservation during the

past fifteen or twenty years, there have been important developments in the utilization of products which were formerly wasted on an enormous scale, namely, the surplus fuel gases produced at iron and steel works and the exhaust steam from the plant at collieries, etc.

It is not always commercially practicable to utilize such waste products having regard to the necessary capital outlay and resultant working costs when compared with the corresponding costs for an equivalent power house comprising high-pressure steam turbines or gas-producers and gas engines, and the designer must work out the relative economies in each particular case. In America, for example, natural gas is transmitted under a pressure of 80 lb. per square inch for long distances. This gas, however, has the high calorific value of approximately 900 B.Th.U. per cubic foot, as contrasted with an average value of about 500 B.Th.U. for coke-oven gas and 90 B.Th.U. for blast furnace gas. The transmission of the latter gases to a central point through expensive pipe lines and by means of expensive compressing machinery becomes uneconomical, and it is found to be cheaper to utilize them at a site near the coke ovens or blast furnaces and to transmit the electrical energy if necessary. In other words, local utilization of such gas and electrical transmission of the resulting energy are cheaper than piping and transmission of the gases with distant utilization.

One of the most notable examples of the utilization of waste heat on a comprehensive scale over a wide area is that afforded by the system of the Power Supply Companies serving the vast industrial district of the north-east coast of England.

In this district a very large quantity of metallurgical coke is manufactured annually, and the waste gases from the coke ovens are estimated as capable of generating some 30,000 K.W. continuously. The waste gases from blast furnaces are of still greater importance, and are estimated as capable of producing about 50,000 K.W. continuously if utilized without being cleaned, and about 170,000 K.W. if cleaned.

The possibilities attaching to an individual works are well indicated in Fig. 168 taken from a paper read by Mr. C. H.

Merz before the Iron and Steel Institute, England, in 1908. This figure shows the estimated daily output and load curve of waste heat at the important coke-oven works of Messrs. Pease & Partners, Crook, Co. Durham. Under a co-operative agreement between the Power Company and the coke-oven owners, the waste heat is transformed into electrical energy and the owners are given back what power they may require, the surplus (representing a very big output) being "pumped" into the high-tension transmission mains for utilization throughout the district.

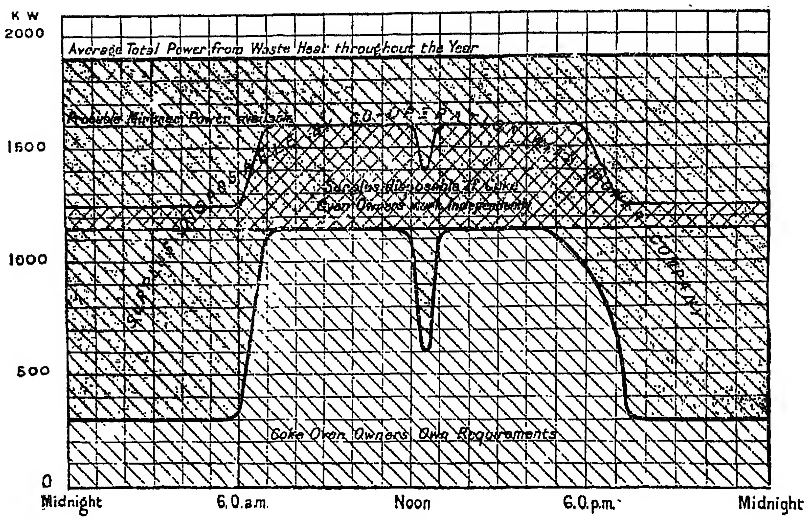


FIG. 168.

Table No. CXIX. contains particulars of a number of the power houses in the north-east coast area at which waste heat is utilized for the generation of high-tension 3-phase current (40 cycles). It is interesting to note that practically all of the prime movers in these power houses are steam turbines, the gaseous fuel being burnt under boilers.

A plan and cross-section of the coke-oven waste heat power house at Weardale are shown in Fig. 169. This station contains four specially arranged gas-heated water-tube boilers and four turbo alternators aggregating 5000 K.W., with a complete

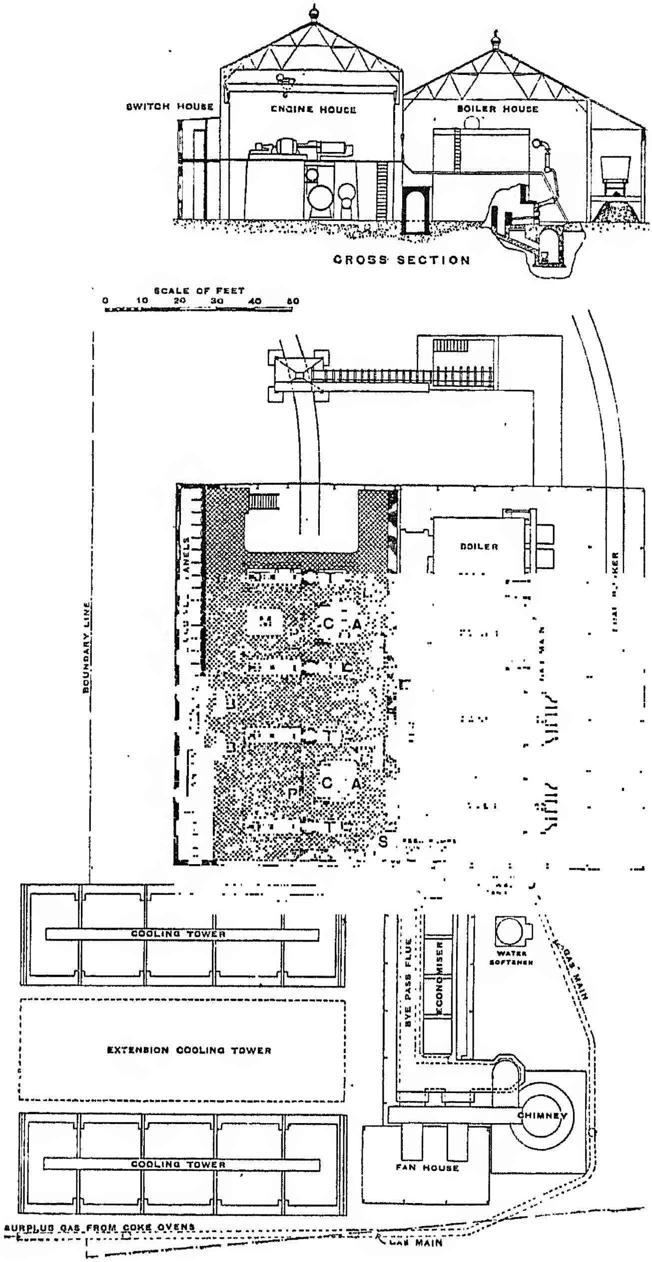

SWITCH HOUSE
ENGINE HOUSE
BOILER HOUSE
CROSS SECTION
SCALE OF FEET
0 10 20 30 40 50
BOUNDARY LINE
BOILER
M
C
A
P
S
COOLING TOWER
EXTENSION COOLING TOWER
COOLING TOWER
BYE PASS FLUE
ECONOMISER
WATER SOFTENER
GAS MAIN
CHIMNEY
FAN HOUSE
SURPLUS GAS FROM COKE OVENS
GAS MAIN

Fig. 169.

TABLE CXIX.

WASTE HEAT STATIONS: NORTH-EAST COAST DISTRICT.

Name or location of station.	Capacity of station.	Source of power.
	K.W.	
Ayresome	2,400	Exhaust steam; surplus live steam.
Bankfoot	6,000	Waste heat and coke-oven gas.
Blaydon	4,200	Waste heat and coke-oven gas.
Bowden Close . . .	4,800	Waste heat and coke-oven gas.
Horden	2,400	Coke-oven gas.
Newport	5,500	Blast furnace and coke-oven gas; live and exhaust steam.
Port Clarence . . .	2,400	Blast furnace gas; exhaust steam.
Tees Bridge . . .	1,125	Exhaust steam.
Weardale . . .	6,250	Coke-oven gas.

equipment of condensers and cooling towers. The floor space occupied by the power house is 5·2 square feet per K.W. with cooling towers and 3·6 square feet per K.W. without, the cooling towers in this instance requiring 1·6 square feet per K.W. installed. More recently, this station has been extended by the addition of a Fullagar gas engine generator having a capacity of 1250 K.W. The engine was built by Messrs. Belliss & Morcom and Messrs. Metropolitan Vickers, Ltd., and is of considerable interest. It has six cylinders 18 inches in diameter, a stroke of 27 inches and a speed of 171·5 R.P.M., and a high efficiency is claimed for it. The cylinders are open ended and valveless, and are arranged in pairs side by side, each pair constituting a unit. Each cylinder is fitted with two pistons, the top pistons of a unit being cross connected to the bottom pistons by oblique rods working externally to the cylinders, so that the stresses set up by the explosions in the latter are distributed over both lines. The engine works on the 2-stroke cycle, each crank thus receiving two impulses per revolution. In addition to the absence of valves, valve gear, and rods, and to the more even distribution of stresses, there is a reduction of weight in this type of gas engine and the crank shaft is relieved from performing negative work. The engine is so arranged that through combined cushioning and inertia the oblique rods are kept in constant tension, and its general construction admits of easy accessibility.

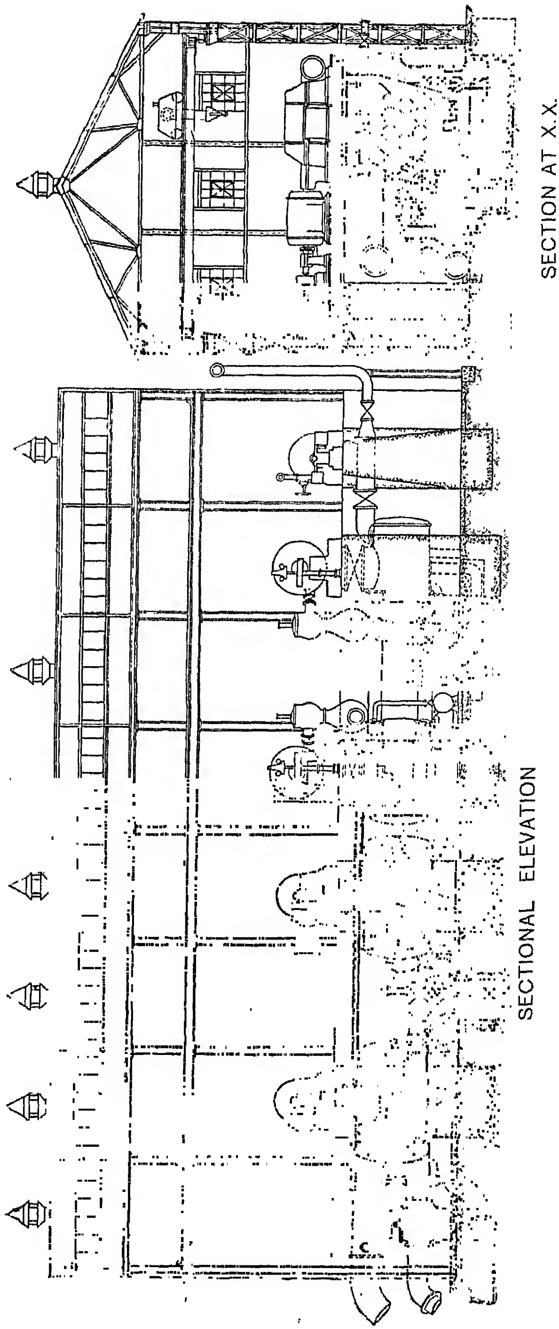


FIG. 170.

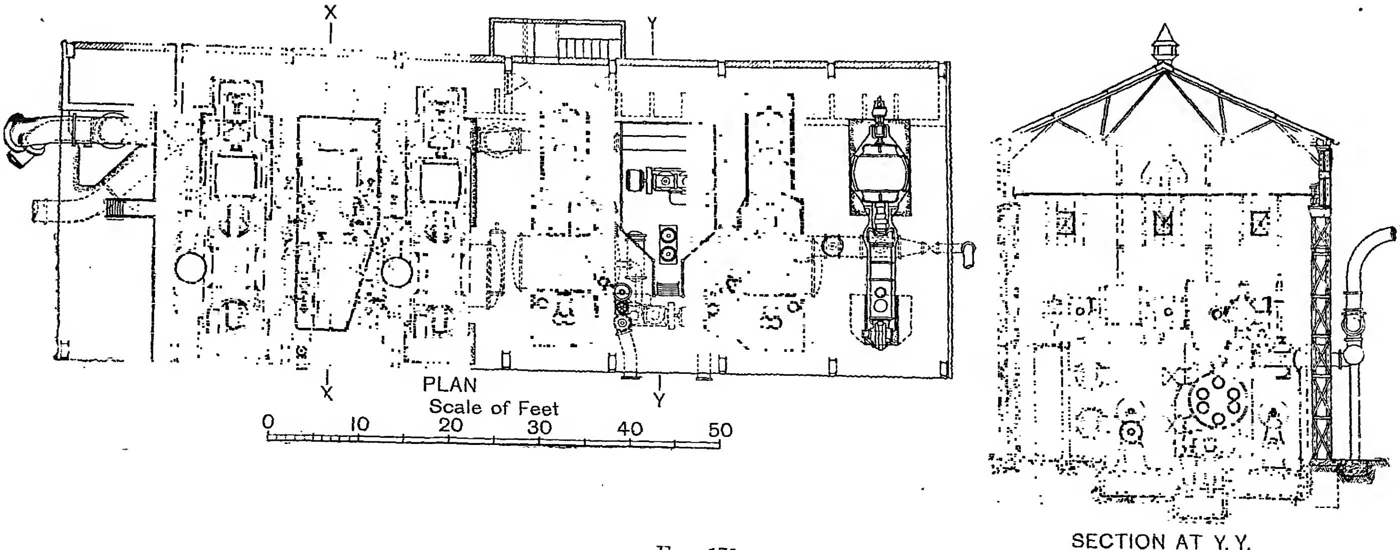


FIG. 171.

Figs. 170 and 171 show a plan and sections of a power house utilizing the exhaust steam from blowing engines. The steam is taken through a superheater to the power house and led to exhaust turbines of some 5500 K.W. output in all. The circulating water for this power house is obtained from the neighbouring river Tees, and a good vacuum is possible. As has been shown previously, this is an important matter with exhaust steam turbines, for the steam consumption at a vacuum of 26 inches is half as much again as that at a vacuum of 29 inches.

The engineer has to utilize the forces of nature at the lowest cost compatible with good and enduring work; he has also to utilize the natural riches of the earth in the most efficient manner possible. The appalling waste of heat which took place during the nineteenth century has at last been realized, and it is owing to the advances in electrical transmission, as well as to the development of the gas engine and steam turbine, that such waste is now being avoided and a greater use made of the stored energy in coal, of which even the present generation is still so prodigal.

CHAPTER XII

HYDRO-ELECTRIC POWER HOUSES

THERE are many countries which are favoured with great natural resources in the form of water power, and the constantly growing applications of and demands for electrical energy coupled with modern developments in long distance electrical transmission, and in the design and construction of hydraulic turbines, have resulted in the utilization of these resources on an enormous scale for the service and convenience of man. Notwithstanding the notable progress in this direction already made in different parts of the world, such as the United States, Canada, New Zealand, Norway, France, Sweden, Italy, and India, the water powers hitherto utilized represent only a small percentage of the estimated available resources, and there is, without question, an immense field for further developments. With regard to Great Britain, it may be broadly said that topographical and other conditions preclude the possibility of many individual water powers of considerable magnitude. Nevertheless, there is undoubtedly a substantial aggregate of small water powers which could be developed and utilized on a much more extensive scale than hitherto to the benefit of the community in many directions.

Commercial Utilization.—The commercial utilization of water power is governed by three main considerations, namely: (*a*) the capital costs involved in the purchase of the water rights, the embankment and training of the falls, the construction of the head and tail races or pipe line, and of the power house; (*b*) the capital cost of any necessary transmission lines and the annual loss of power consequent upon transformation and transmission; and (*c*) the resultant costs of generation as

compared with those for a steam, gas, or oil-driven power house possibly at some more convenient site nearer to the load.

It is not within the scope of this book to enter into a detailed consideration of the economic aspects of water power developments, or of the design and construction of hydraulic turbines and accessory plant available for such developments. To discuss these matters at any length would require a treatise by itself, and the reader must therefore be referred to the various standard works on the subject. The Author proposes, however, to indicate on broad lines the general problems which confront the designer in dealing with hydro-electric schemes, and to describe a few leading types of power house in connection with the different classes of water power developments.

Selection of Site.—In settling upon the site for a hydro-electric power house, the following important matters must be considered:—

(*a*) *Available Supply of Water.*—Whenever possible, the estimates of the average quantity of water available for a power development should be based on actual measurements of river flow. In cases where such measurements have not been taken, then reliance has to be placed on rainfall records taken at various locations on the gathering ground, and allowances have to be made for losses due to evaporation, percolation, etc., in arriving at the average volume of water discharged. The latter method is, of course, liable to serious error in localities where the river may become frozen during winter months or where the gathering ground may be subject to heavy snowfall. In all cases, however, it is essential that the basic observations from which the estimates are prepared should have been taken for a sufficient number of years to yield reasonably reliable figures not only for the average discharge but also for the maximum and minimum variations from the average. It is obvious that an over-estimate of the discharge, resulting in expenditure upon civil engineering and hydraulic works of an unnecessary size, may prove a serious commercial handicap to a scheme when developed.

(*b*) *Facilities for Storage of Water.*—On account of variations in the rainfall, it is only in exceptional cases that a uniform

output of power can be obtained by utilizing the unregulated flow of a river. Although small water powers giving a variable output can often be advantageously developed, for example, for supplementing the output of a power house depending upon fuel, even in such cases the value of the water power would be considerably enhanced if the flow of water could be economically regulated. In the case of practically all but the smallest class of water powers, the provision of a storage basin or reservoir for equalizing the flow is essential, so that an excess of water at certain periods can be rendered available for maintaining the output during times of insufficient flow or drought. The provision of economical storage requires most careful study of the topography and geology of the gathering ground in order that natural formations may be utilized to the maximum advantage, for example in the selection of the site for a dam or the location for a pressure tunnel. As the cost of these works usually represents a very large proportion of the total cost of development, ranging sometimes up to 70 or 80 per cent., the highest skill and judgment must be applied to this section of a hydro-electric scheme to secure the maximum limit of storage consistent with a commercially sound expenditure.

(c) *Available Head of Water.*—In determining the most advantageous head for a given water power scheme, account has to be taken not only of the topography of the watershed, and of the average and minimum flow, but also of the effect of the piling up of water in the tail race caused by the turbine discharge or by floods. In the case of low falls on unregulated rivers, the effective head will be subject to fluctuations and may sometimes be reduced to nil owing to the drowning of the tail race. For a given output of power, every increase in the effective head involves a reduction in the amount of water to be stored and passed through tunnels, flumes, pipe lines, and turbines, and hence in the cost of development. The importance of securing the largest effective head consistent with other characteristics of a scheme and with commensurate capital expenditure is therefore apparent.

There are various other factors, in addition to the above, which must be considered before deciding upon the best position

for the power house. When it is proposed to utilize the power on the spot for the manufacture of electro-chemical or electro-metallurgical products, due regard must be had to the transport facilities necessary for bringing the raw materials to the factory and for disposing of the finished products. When the power is to be transmitted for use at a distant factory or for general industrial purposes, the choice of a site for the power house may be influenced by an economic limit to the length of transmission line permissible in a particular case and by the route available for its erection.

Measurement of Water Flow.—A few observations regarding the measurement of water flow will be useful to the designer.

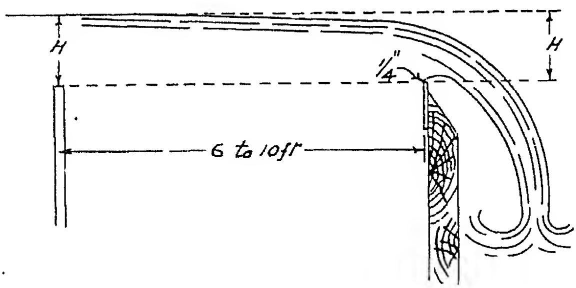


FIG. 172.

In the first place, the velocity of water in motion due to a given head is obtained by means of the formula

$$v = \sqrt{2gh}, \text{ or more simply } v = 8{\cdot}03\sqrt{h},$$

where v is the velocity, in feet per second;

h is the head, in feet; and

g is the gravity value, taken at 32·2.

A fairly accurate calculation of the volume of water flowing past a particular point on a river can be made by constructing a weir as shown in Fig. 172. In cases where the weir is the full width of the stream to be measured, Francis has determined that the volume of water flowing (in cubic feet per second) is as given by the formula—

$$V = CB\sqrt{H^3}$$

where C is a coefficient having the value of 3·33;

B is the width of the weir, in feet; and

H is the true depth of the water on the weir, in feet.

If the weir is contracted on one side or both, then the formula becomes

$$V = 3{\cdot}33(B - 0{\cdot}1nH)\sqrt{H^3}$$

where n is the number of contractions.

In some cases, it is necessary to use a submerged weir, and with a weir of the form shown in Fig. 173, the volume in cubic feet per second is given by the formula—

$$V = K\,.\,B\left(H + \frac{h}{2}\right)\sqrt{H - h}$$

where B is the width of the weir, in feet;

H and h are the dimensions shown in Fig. 173, in feet; and

K is a coefficient depending upon the value of $h \div H$.

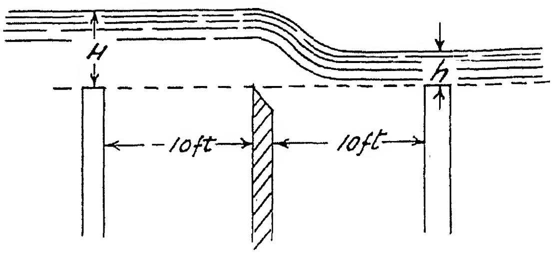


FIG. 173.

The values of the coefficient for different values of $h \div H$ are as follows:—

$h \div H$	K
0·2	3·30—3·36
0·4	3·15—3·21
0·6	3·12—3·17
0·8	3·11—3·16
0·9	3·15—3·21

The accuracy of the weir method is stated to be within 4 per cent.

The flow of water may also be measured by a float at various points—not less than 10—across the width of the stream, selecting a place where the banks are approximately parallel and the bottom fairly smooth. The average time taken to float between two points of observation is then noted. The float should be cylindrical and so weighted that the submerged end is only just

clear of the bed of the stream, if shallow. A survey is then made of the bed of the stream so as to get its sectional area, measured from the top of irregularities such as boulders lying in the bed of the stream. The average area of the stream in square feet multiplied by the ascertained average velocity in feet per minute will give the flow in cubic feet per minute. The accuracy of this method is stated to be within 12 per cent.

Finally, the velocity may be measured by a meter of the revolving type, having vanes rotated by the water current, or by a deflecting meter, in which a vane is deflected by the current and brought back to zero by the torsion of a steel wire. These meters are read about one foot below the surface at each of the points where the contour of the bed is taken, and the average of the readings thus obtained is multiplied by 0·85 to get the average velocity. Or the meter can be slowly lowered to the bed at each measuring point and slowly raised to the surface, and the average at each point taken as the real measure. Or, again, the meter is held at a point 0·6 of the actual depth of the stream at each place, and the average of all such readings across stream may be taken as the real value. The readings of the meter are referred to tables, which give the flow of water within 10 per cent.

Each of the methods described above should be tried in succession and a mean taken of the three results. Both minimum dry weather flow and flood-water observations must be taken.

A further rough check can be made on a river flow by ascertaining the average and minimum rainfalls and the area of the watershed drained by the river in question. The flow by actual measurement will, of course, be a good deal less owing to the effect of evaporation, percolation into underground springs and streams, etc., and the various geological conditions.

Flow through Head Races and Penstocks.—The flow of water under a head of H feet through the openings of head races, penstocks, etc., is given in cubic feet per second by the following general formula—

$$V = k \,.\, LD\sqrt{2gH}$$

where L and D are the length and depth of the opening, both

expressed in feet, and k is a coefficient having the approximate value of 0·61 for openings of the kind in question.

For rectangular openings, the formula becomes

$$V = 4{\cdot}895LD\sqrt{H}$$

while for circular openings of diameter D feet, where H is greater than 2D, the formula becomes

$$V = 3{\cdot}84D^2\sqrt{H}.$$

Kutter's formula for the flow through a pipe or canal is as follows—

$$V = CA\sqrt{S}\sqrt{R}$$

where A is the wetted cross-section, in square feet;

S is the fall, in feet per foot;

R is the mean hydraulic radius, i.e. the ratio of the wetted cross-section to the wetted perimeter; and

C is a constant depending on the coefficient of roughness.

The flow of water through a pipe depends on the head, the length of pipe and the bends, and the coefficient of roughness. The total resistance to flow is made up of three components—

(*a*) Velocity head or the height through which a body must fall to acquire the velocity of the water in feet per second flowing through the pipe—

$$H_v = \frac{v^2}{2g}.$$

(*b*) Entry head, or that necessary to cause the fluid to enter the pipe, roughly half the velocity head.

(*c*) Friction head, or that necessary to overcome the friction in the pipe.

If the pipe line is very short, a maximum velocity of $0{\cdot}1\sqrt{2gH}$ may be adopted; but if the pipe line is long, this velocity must be reduced so as to avoid friction losses.

The following values for the coefficient of roughness are generally taken:—

0·012 for concrete and open wood flumes and pipes 3 feet and more in diameter, with high water velocities.

0·013 for pipes from 3 feet to 6 feet in diameter, with low water velocities, and for large cement-rendered tunnels.

0·0135 for brickwork penstocks over 3 feet in diameter, and cast iron and steel riveted pipes from 8 to 20 inches in diameter under 75 to 150 lb. pressure.

0·015 for rough concrete races or tunnels (where the interior faces are not smooth rendered) with moderate water velocities, and for open concrete canals with low water velocities.

0·017 for tunnels in hard rock roughly faced, and very large open concrete-lined canals.

0·02 for races lined with rough masonry, canals in earth, etc.

Civil Engineering Works.—Difficult and costly civil engineering operations have frequently to be undertaken in developing a water power, and the importance of a thorough survey of the country to locate the best positions for storage reservoirs, dams, pressure tunnels, pipe lines, or flumes, and the power house and tail race cannot be too strongly emphasized.

Considerable preliminary operations, involving the diversion of a very substantial volume of water, have sometimes to be undertaken at a heavy expenditure so as to enable the head works to be soundly constructed. Such a case arose at Gullspång, in Sweden, where an expensive tunnel had to be cut through gneiss to divert the river while the original bed was prepared and strengthened to enable the power house and sluices to be constructed. Questions concerning the construction of costly masonry dams, of spill-ways for excess or compensation water, of sluices properly proportioned to control the flow under varying conditions, of salmon and eel passes to avoid interference with fishing rights and spawning grounds, and of tail races which will obviate flooding or the undue raising of the backwater level, are some of the many matters which require actual experience in this class of work. In some cases it may be found cheaper to build a long head race or canal, or to excavate a pressure tunnel, or to lay long lines of pipes; in others, it may be cheaper to excavate a longer tail race. At some sites, the tail race may be liable to become partly filled up with detritus brought down with the water; or to become piled up with flood water with a consequent great reduction in the head.

Lengthy tail races are also liable to become frozen in some climates and are generally to be avoided. Where pipe lines have to be laid, a careful survey is necessary in order to select the best and easiest route possible with the view of fixing the pipes in position under the least costly conditions with suitable anchors to avert landslides, and of providing for the construction of relief ways, and so forth. All these matters call for the best applied civil engineering practice, so as to ensure that the available water is utilized to the maximum advantage under the best commercial conditions. Every additional hundred pounds spent unnecessarily becomes practically a dead charge on the undertaking for one or two generations.

Storage Reservoirs.—The provision of storage reservoirs and the construction of dams, which are usually necessary in this connection and also for raising the available head, are matters of special importance demanding some further observations.

The extent to which storage is necessary in a given case is governed by the nature of the prospective load on the power house and also by the head of water available at the site. In some countries it is customary to give three different classes of supply, namely: (*a*) guaranteed full year supply; (*b*) supply for restricted hours; and (*c*) supply liable to be cut off in periods of severe drought or during exceptional wintry conditions. It is obvious that for a given maximum load, the first-named class of supply necessitates the largest storage provision. In the case of hydro-electric power houses operating at a very high annual load factor, say of 90 per cent. or over, the storage necessary for ensuring a continuous output based on average flow and notwithstanding weekly, monthly, and yearly variations in rainfall, would seldom be economically justifiable. Such storage would only be drawn upon to its full capacity at infrequent intervals whereas the undertaking would be permanently burdened with the capital charges on the works. When a full year's supply for a long period has to be guaranteed, the economical limit to which storage can be carried may therefore require the sacrifice of a portion of the potentialities of the site and the development of a power which is smaller than that based on the average flow.

The effect of the available head upon the storage necessary for maintaining a given output is indicated by the figures in Table No. CXX., which gives the average number of kilowatt-hours (and horse-power hours) obtainable per acre-foot of storage area for heads varying from 5 to 1000 feet.

TABLE CXX.

AVERAGE KILOWATT-HOURS AND HORSE-POWER HOURS PER ACRE-FOOT OF STORAGE WITH DIFFERENT HEADS.

Head.	Available energy.		Head.	Available energy.		Head.	Available energy.	
ft.	H.P. hrs.	K.W. hrs.	ft.	H.P. hrs.	K.W. hrs.	ft.	H.P. hrs.	K.W. hrs
4	5·5	4·103	150	206·25	153·863	580	797·50	594·93
5	6·88	5·129	160	220·0	164·120	590	811·25	605·19
6	8·25	6·155	170	233·75	174·378	600	825·00	615·45
7	9·62	7·180	180	247·50	184·635	610	838·75	625·71
8	11·00	8·206	190	261·25	194·893	620	852·50	635·96
9	12·37	9·232	200	275·00	205·150	630	866·25	646·22
10	13·75	10·258	210	288·75	215·408	640	880·00	656·48
11	15·12	11·283	220	302·50	225·666	650	893·75	666·74
12	16·50	12·309	230	316·25	235·923	660	907·50	676·99
13	17·90	13·335	240	330·00	246·180	670	921·25	687·25
14	19·24	14·361	250	343·75	256·438	680	935·00	697·51
15	20·62	15·386	260	357·50	266·69	690	948·75	707·77
16	22·00	16·412	270	371·25	276·95	700	962·50	717·92
17	23·37	17·438	280	385·00	287·21	710	976·25	728·18
18	24·75	18·464	290	398·75	297·47	720	990·00	738·44
19	26·13	19·489	300	412·50	307·72	730	1003·75	748·70
20	27·50	20·515	310	426·25	317·98	740	1017·50	758·95
21	28·87	21·54	320	440·00	328·24	750	1031·25	769·21
22	30·25	22·566	330	453·75	338·50	760	1045·00	779·47
23	31·62	23·592	340	467·50	348·75	770	1058·75	789·72
24	33·00	24·618	350	481·25	359·01	780	1072·50	799·98
25	34·37	25·644	360	495·00	369·27	790	1086·25	810·24
26	35·75	26·670	370	508·75	379·53	800	1100·00	820·50
27	37·12	27·699	380	522·50	389·78	810	1113·75	830·76
28	38·49	28·72	390	536·25	400·04	820	1127·50	841·01
30	41·25	30·772	400	550·00	410·30	830	1141·25	851·27
32	44·00	32·824	410	563·75	420·56	840	1155·00	861·53
35	48·12	35·901	420	577·50	430·81	850	1168·75	871·79
40	55·00	41·130	430	591·25	441·07	860	1182·50	882·04
45	61·87	46·159	440	605·00	451·33	870	1196·25	892·30
50	68·75	51·288	450	618·75	461·59	880	1210·00	902·56
55	75·62	56·416	460	632·50	471·84	890	1223·75	912·82
60	82·50	61·538	470	646·25	482·10	900	1237·50	923·07
65	89·37	66·667	480	660·00	492·36	910	1251·25	933·43
70	96·25	71·803	490	673·75	502·62	920	1265·00	943·69
75	103·12	76·931	500	687·50	512·87	930	1278·75	953·95
80	110·00	82·060	510	701·25	523·13	940	1292·50	964·20
90	123·75	92·318	520	715·00	533·39	950	1306·25	974·46
100	137·50	102·575	530	728·75	543·65	960	1320·00	984·72
110	151·25	112·833	540	742·50	553·90	970	1333·75	994·98
120	165·00	123·092	550	756·25	564·16	980	1347·50	1005·23
130	178·80	133·348	560	770·00	574·42	990	1361·25	1015·49
140	192·50	143·605	570	783·75	584·68	1000	1375·00	1025·75

Low fall developments involve the handling of large volumes of water, and under average conditions, the provision of storage necessitates the flooding of valuable land. Careful consideration has therefore to be given to the question whether it will be commercially profitable to incur any substantial expenditure on the construction of storage works. The advantages of providing even a moderate amount of storage should not, however, be overlooked, for in the case of a power house operating at a low annual load factor it may prove economical to construct a larger installation than would have been justifiable had no storage whatever been available.

The levels and contours of the ground offering facilities for storage must be carefully investigated, and similar observations must also be made as regards land already submerged by lakes,

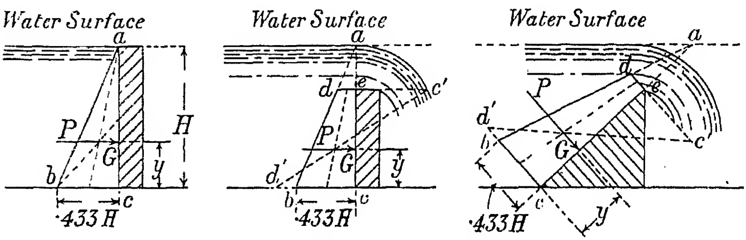


FIG. 174.

etc., in order to arrive at an accurate estimate of the storage capacity actually available. The possible formation of ice in shallow basins as well as evaporation have to be allowed for, the amount of storage lost by ice formation being in the ratio of the depth displaced by the ice to the working depth of the basin.

Construction of Dams.—In the construction of dams expert civil engineering and geological knowledge are required. Questions such as excavation into rock so as to effect a good junction between the concrete dam and solid rock; elimination of leakage, with its possible underpinning of the dam; and the effects of springs, or of ice-floes, flood waters, etc., all call for a special experience, and assistance should be obtained from those who have had experience in this important class of work. A few observations may, however, be of use here.

The total pressure exerted on any dam (see Fig. 174) is equal

to the area of the pressure diagram (a, b, c, in the first sketch, and b, d, e, c, in the other two). The centre of the pressure passes through the centre of gravity perpendicular to the dam surface.

The pressure at any point, in lb. per square inch, is given by $P = 0·433D$, where D = depth from surface in feet.

The moment about the point c is given by $M = Py$, and the total pressure in lb. exerted on any dam is

$$P = 0·433HA$$

where A is the area of submerged dam in square feet, and H the head of water in feet above the geometrical centre of the submerged portion of the dam.

Dam at Gullspång.—An interesting example of dam construction, described by A. V. Clayton ("Journal, Institution of Electrical Engineers," Vol. 45, 1910), is illustrated in Fig. 175 which shows a section of the river bed and an elevation and plan of the dam at Gullspång, situated between the lakes of Skagen and Vänern in Sweden.

It will be seen that the rock underlaid the river bed at some depth. A straight part of the dam was constructed on the gravity principle and built directly on the solid rock bed, the straight portion being brought out as far as possible so as to reduce the length of the arched portion. The arched part of the dam depends for its stability on its arch-like property, the crown being against the stream or head of water and buttressed against the straight parts of the dam on each side, which thus act as abutments. The employment of this method enabled a great saving to be made both in the amount of excavation and in the materials employed. Fig. 175 shows that the section of the river bed which would otherwise have had to be excavated is practically equal to the profile of the dam itself. If the extra width of base required for a gravity dam be calculated, it will be found that the cubical contents of this extra portion are as great as those of the existing dam. If a gravity dam had therefore been constructed throughout, double the quantity of the materials actually used would have been required in addition to all the extra excavation.

The face of the dam is rendered with cement, and the bottom

caulked with stamped clay to prevent leakage. Fifty regulating sluices are provided, grouped in ten openings of five each. The sluices are constructed of wood working in I section steel girder frames. A large spillway is provided in the middle of

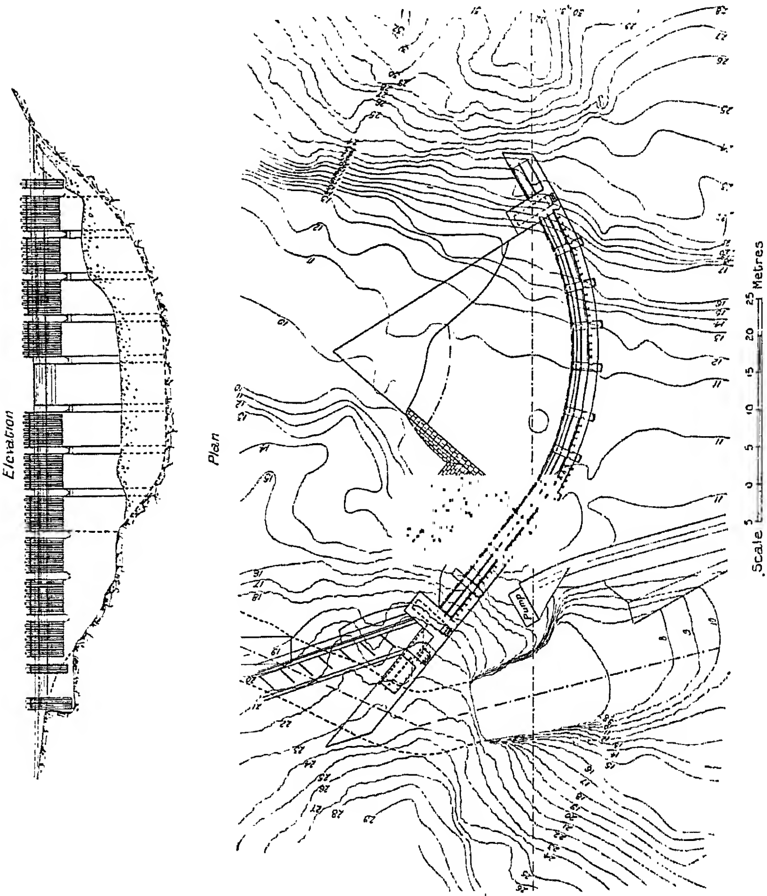


FIG. 175.

the dam, to clear away loose ice, and a salmon pass and two eel passes are also provided.

Design of Power Houses.—In the design of power houses for hydro-electric work, care has to be taken in the selection of materials, as otherwise accidents may happen causing loss of life

and a shut down of the plant. For instance, the outer cases of flumes were formerly made of cast iron, a practice now abandoned. On one occasion an outer case burst owing to a flaw in the casting, thereby causing loss of life and much damage to the plant before the inlet gates could be shut.

The lower portions of power houses are usually constructed of concrete—sometimes reinforced—and the upper parts, above flood-level, of brickwork. Very heavy dead weights have to be supported, and very heavy thrusts and tilting effects due to the water pressure have to be provided for.

The design should provide for expansion and contraction, so as to eliminate chances of cracks in the concrete. Thus it is best to construct the forebays each by itself, unconnected with one another. The effects of severe frosts on cracks in the concrete have to be considered, and great attention must be paid to this, and also to the chances of leakage between the flume plates and the concrete, while at the same time allowing for differences of expansion between the flume plates and the surrounding concrete.

Water Turbines.—A good deal depends upon the selection of the type and size of water turbine best suited to the requirements of a given hydro-electric development, and although the question of turbine design is not within the scope of this book some notes may be given regarding the principal characteristics of modern turbines.

During the evolution of the water turbine, many sub-types have been designed, but in all modern water power developments the choice now practically lies between the two following main types, namely :—

(*a*) The reaction type, practically the converse of the screw propeller ; and

(*b*) The impulse type, operated by the direct impact of a jet of water from a nozzle.

For low and medium falls, radial inward flow reaction turbines of the Francis type have generally been adopted in recent years, whereas in the case of high falls, tangential flow impulse turbines (Pelton wheels) have usually been installed.

Speed and Efficiency of Turbines.—Low-head turbines when

employed for driving electrical generators require to be designed for as high a speed as is consistent with reasonable efficiency. Some of the older types of turbines were connected to their generators through gearing, thus reducing the efficiency and increasing the cost. The recognition of these drawbacks and also of the economic possibilities attaching to the development of low falls for electrical purposes has been responsible for great progress in the design of reaction turbines capable of giving the highest possible speed under a given head and for a given output. These designs are also characterized by a high efficiency under working conditions corresponding to a considerable range of gate openings.

There is a critical speed at which any turbine operates under the most economical conditions, and if this speed is exceeded without a decrease in the diameter of the runner, the efficiency is reduced. The peripheral speed of turbines has a relation to the theoretical velocity of the water falling freely through a height equal to the distance between head race and tail race levels. This peripheral speed ranges from 60 to 80 per cent. of the theoretical water velocity in the case of reaction turbines, and from 40 to 50 per cent. in the case of impulse turbines.

It is now usual to compare the performances of turbines of different sizes under different conditions of operation by reference to their "specific speeds". This expression denotes the speed of a geometrically similar model of the turbine in question designed to give an output of 1 B.H.P. under a head of 1 foot. If a turbine has a speed of N revolutions per minute and an output per runner of P brake horse-power under a head of H feet, its specific speed N_s is given by the equation

$$N_s = \frac{N \times \sqrt{P}}{\sqrt[4]{H^5}} = \frac{N \times \sqrt{P}}{H\sqrt{\sqrt{H}}}.$$

For given values of N and H, the output is proportional to the square of the specific speed, while for a given head and output, the actual speed of the turbine is proportional to its specific speed.

There have been notable advances in recent years in the specific speeds and capacities of turbine units of the Francis

type, and efficiencies ranging between 80 and 90 per cent. have been obtained with specific speeds of from 25 to 90. In normal practice, a specific speed of about 12 is as low as should be employed having regard to the falling off in efficiency.

In the case of Pelton wheels for high falls, the question of keeping the speed within reasonably moderate limits has sometimes to be considered. Moreover, for high efficiencies, careful attention has to be given to the relative diameters of the water jet and of the wheel; as a general rule this ratio should not exceed $\frac{1}{12}$. Pelton wheels give the highest efficiencies with specific speeds ranging from 1 to 4; and for wheels with a single runner and jet, the upper limit for the specific speed may be taken at from 5 to 7. When the maximum specific speed of a single jet single runner under a given head is too low for the electrical generators contemplated, then a higher speed can be secured by the use of two or more jets or runners.

It may be noted that in the case of some recent high fall developments with heads up to 600 feet and more, Francis reaction turbines of large capacity and with low specific speeds have been installed instead of Pelton wheels.

Speed Regulation.—Automatic governing devices of a high degree of excellence are available and have played an important part in contributing to the success of hydro-electric developments. The various forms of mechanical governor formerly in use were quite unsuitable for modern requirements and have been superseded by the hydraulic governor operated by a fluid under pressure, usually oil. The whole object of a well-designed governor for hydro-electric units is to secure a sensitive and positive control without any danger either of overrunning or of hunting. The modern oil-pressure governor consists essentially of a centrifugal pendulum controlling a distributing valve which allows oil under pressure to pass to one side or the other of the piston of a servomotor. This piston actuates the devices controlling the supply of water to the turbine and also, through relay mechanism, returns the distributing valve to its central position. Through the intervention of a dash-pot, which acts temporarily as a rigid connection, the governor also actuates a relief valve or a jet deflector and thereby obviates an undue rise

of pressure in the pipes supplying water to the turbine when the latter is suddenly shut off. For detailed information concerning the construction and operation of oil-pressure governors, the reader should consult the standard works on water turbine plant.

Reaction Turbines.—The reaction or pressure turbine is the cheapest type and is particularly suitable for low fall water powers although equally well adapted for falls of 100 feet and over. In this type of turbine, the buckets must be completely filled with water and the runner must be supplied with water all over its circumference. Otherwise, if the runner is submerged, the buckets after moving away from the guide blades will be full of still water which has to be displaced when the buckets come round again and power is thus wasted in moving this dead water round with the wheel. If the runner is not submerged, then water is used in filling the buckets which have emptied on leaving the guide blades before the full head can be utilized.

Reaction turbines are only affected by backwater to the extent that the tail race level is increased, and can be installed between head water and tail race levels with a draught or suction tube if there is enough water above the turbine to prevent air from being drawn into it. A part of the effective head is then obtained from the suction on the tube, but the suction head should not exceed about 25 feet. Careful attention must be given to the design of the draught or suction tube, as if properly constructed, it also enables a portion of the energy due to the velocity of the water leaving the runner to be recovered.

The control of the water supply to the runner is effected by means of a cylinder gate, register gate, or movable guide blades operated from the automatic governor, the third form or wicket-gate now being almost invariably adopted.

The turbine can be mounted on a horizontal or vertical shaft according to the conditions at a particular site, and in the case of low or medium falls two or more runners may be arranged on a common shaft in order to obtain a higher speed and an economy in the cost of the direct-driven generators. This practice has been commonly adopted in Europe. With the

modern high capacity runner, however, there are many advantages in using single vertical turbine units for low or medium falls, for example, reduced foundations, a smaller number of units for a given output, and an economy in the cost of development.

The following Table No. CXXI. gives the leading particulars and approximate pre-war prices of a number of sizes of horizontal reaction turbines :—

TABLE CXXI.

HORIZONTAL REACTION TURBINES.

B.H.P.	Head: Feet. / Metres.	50 / 15·25	80 / 24·4	100 / 30·5	120 / 36·57	150 / 45·72	180 / 54·86
250	R.P.M.	460	600	665	720	720	720
	Cubic ft. per min.	3530	2206	1765	1470	1175	980
	Weight (t. & cwts.)	4 : 16	4 : 4	4 : 1	4 : 0	3 : 16	3 : 10
	Approx. price (pre-war)	£295	£255	£245	£240	£225	£210
500	R.P.M.	300	488	500	500	500	600
	Cubic ft. per min.	7060	4412	3530	2940	2350	1960
	Weight (t. & cwts.)	8 : 16	8 : 0	7 : 1	6 : 0	5 : 5	4 : 10
	Approx. price (pre war)	£410	£370	£345	£300	£290	£280
1000	R.P.M.	230	333	428	428	428	428
	Cubic ft. per min.	14120	8825	7060	5880	4710	3920
	Weight (t. & cwts.)	13 : 8	12 : 9	10 : 14	9 : 18	9 : 6	8 : 4
	Approx. price (pre-war)	£530	£505	£485	£460	£445	£420
1500	R.P.M.	187	273	333	375	400	400
	Cubic ft. per min.	8300	13300	10600	8820	7060	5880
	Weight (t. & cwts.)	24 : 0	22 : 2	21 : 0	19 : 2	17 : 14	16 : 0
	Approx. price (pre-war)	£860	£815	£785	£755	£715	£670

Single-runner units of very large size are now built; for example, the vertical turbines installed at Cedar Rapids in Canada for a head of 30 feet have a capacity of 10,800 B.H.P. and a speed of 55·6 R.P.M.

Pelton Wheels.—The tangential flow impulse turbine or Pelton wheel can be used for falls ranging from 100 feet upwards, and is almost invariably employed for very high falls. In this type of turbine, a jet of water from a nozzle is directed

upon buckets carried by the wheel, driving the latter by impact and also by the reactive effect of the water, resulting from the buckets being curved to discharge in the reverse direction. The efficiency of the Pelton wheel is independent of the volume of water supplied to it, and the supply need not be to the entire periphery as is necessary in the case of reaction turbines. On the other hand, the wheel must run clear of the tail water.

The buckets are designed so as to obviate shocks and eddies and to deflect the water gradually from its original direction.

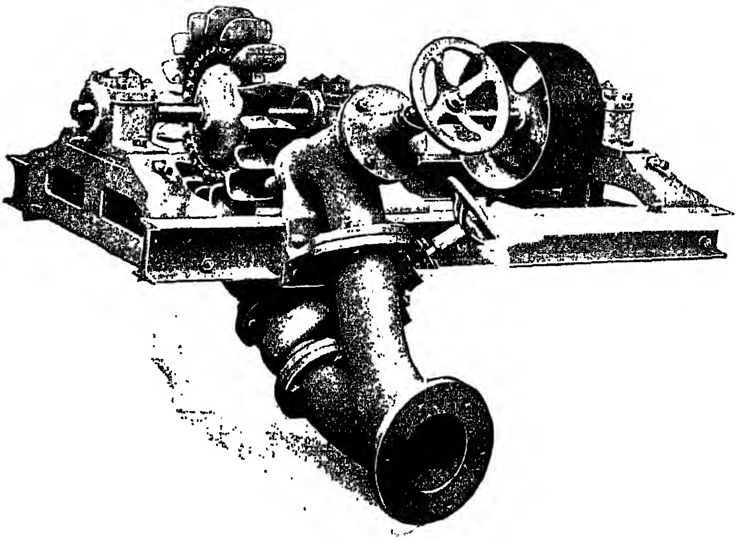


FIG. 176.

They are provided with a median edge for dividing the jet, side thrust thus being neutralized.

The design of the nozzle is also an important matter, and it is now customary to employ a circular form with a concentric regulating needle of "pear" shape. This type of nozzle gives a smooth and solid stream of water free from the spraying appearance of an ordinary jet. The regulating needle is controlled by the automatic governor which also operates a deflector, the latter cutting into the jet and diverting the water away from the buckets upon a sudden discharge of the load and afterwards resuming its normal position tangential to the jet when

the needle, under the action of a dashpot, has taken up its new position. Under gradual changes of load the deflector remains inactive.

Instead of using a single nozzle and wheel, a higher speed for a given fall can be obtained by dividing the water supply among two or more nozzles acting on a single wheel or between two or more wheels on a common shaft. An illustration of a two-jet Pelton wheel as manufactured by Messrs. Gilkes & Co., Kendal, England is given in Fig. 176.

Another view of a two-jet Pelton wheel showing the automatic governing device is given in Fig. 177.

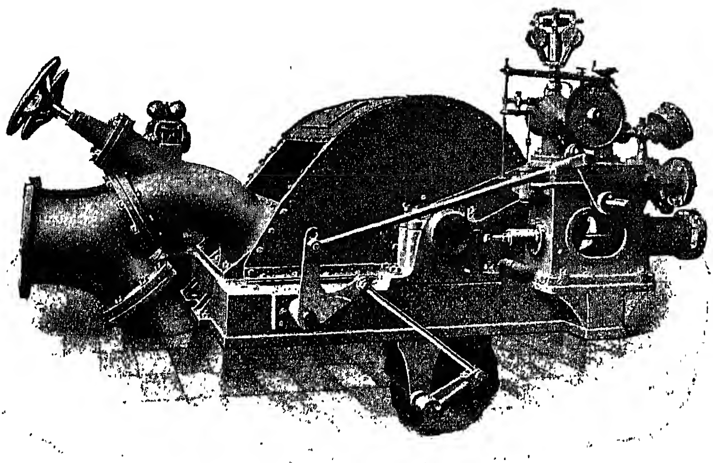


FIG. 177.

A Pelton wheel of 900 H.P. constructed for the Kartari Falls power house, Nilgiri Hills, India, is shown in Fig. 178. The available head is 630 feet, and as a speed of 400 R.P.M. had to be adopted for electrical reasons, the turbine had to be designed accordingly. The diameter of the wheel measured to the point of impact of the jet is 54 inches, and the total diameter is 5 feet. The wheel centre is of cast steel and the buckets of steel alloy are bolted on separately by turned bolts. The shaft is $6\frac{1}{2}$ inches in diameter and of the self-oiling type.

The supply pipe has a diameter of 24 inches, and the single round nozzle of steel alloy is provided with a regulating spear

rod of Delta metal with a phosphor bronze end. The spear rod is operated by an hydraulic relay cylinder, or in an emergency by hand. The automatic governor is of the hydraulic type and is chain-driven from the turbine shaft. The inlet pipe is provided with an automatic inlet valve designed so as to open

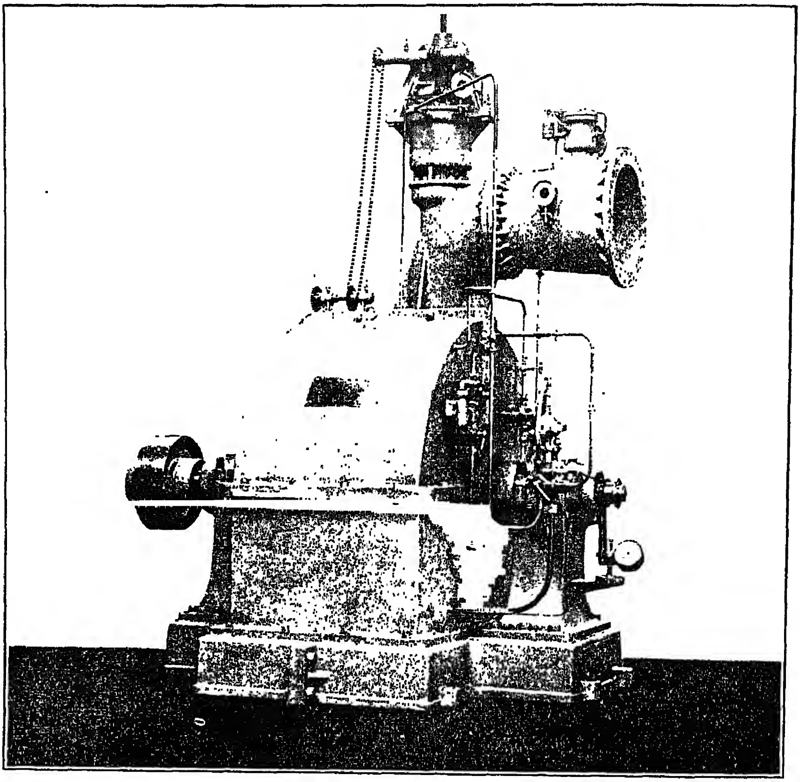


Fig. 178.

instantaneously with a slight increase of pressure and to close down slowly. This valve obviates any surging of the pressure caused by spring-loaded relief valves.

In cases where two or more jets are used with a single wheel the design must be such as to avoid interference between the discharge from the buckets and any of the jets or there will

be a loss of efficiency. If it is necessary to divide the water supply, it is preferable to use two or more wheels on a common shaft each with a single jet.

The leading particulars and approximate pre-war prices of a number of typical Pelton wheels are set out in Table No. CXXII.

TABLE CXXII.

PELTON WHEELS.

Diameter of wheel. Inches.	Fall in feet. / Fall in metres.	250 / 76·19	300 / 91·43	350 / 106·6	400 / 121·9	500 / 152·3	600 / 182·8	700 / 213·3
72	B.H.P.	265	350	440	535	760	980	1250
	R.P.M.	197	217	234	250	279	306	330
	Cubic feet per minute	747	822	889	941	1064	1147	1250
	Weight: tons	4·75	4·75	4·75	4·75	4·75	4·75	4·75
	Approximate pre-war cost: £	245	245	245	245	245	245	245
60	B.H.P.	184	240	305	375	525	675	850
	R.P.M.	237	261	281	301	336	368	396
	Cubic feet per minute	519	564	616	660	735	790	850
	Weight: tons	4	4	4	4	4	4	4
	Approximate pre-war cost: £	200	200	200	200	200	200	200
48	B.H.P.	119	155	195	235	330	440	550
	R.P.M.	296	325	351	375	420	460	496
	Cubic feet per minute	336	364	394	414	462	515	550
	Weight: tons	3·1	3·1	3·1	3·1	3·1	3·1	3·1
	Approximate pre-war cost: £	170	170	170	170	170	170	170

Check on Turbine Consumption.—A check upon the water consumption in hydro-electric power plants is very necessary in many cases, as the supply of water is not unlimited, and the extra cost of impounding is a serious consideration as regards capital outlay.

In many new plants Venturi "throats" can be inserted and an accurate check taken. In existing plants, however, this cannot be so easily done, but a Pitot tube which rates the nozzles can be utilized in such cases. In this connection, reference may be made to the able paper by Mr. W. R. Eckhart read before the Institution of Mechanical Engineers in 1910.

Low-Fall Water Powers.—A simple and typical arrangement

of a low-fall power house on a river is illustrated in Fig. 179. A dam A is constructed to raise the water level and to provide storage or pondage. An intake B allows the water to flow through sluices C to a penstock D, from which it passes into a head race E, then through racks F into a forebay G and finally through the turbines under the control of the turbine guide vanes or gates. The turbines discharge into a tail pit H and tail race I to the downstream or backwater.

In low-fall plants the water is led to the turbine in an open head race in which the velocity is kept as low as possible, viz. about 2 feet per second, so as to minimize losses through eddies and friction. The guide vanes must be covered by at least 5 feet of water.

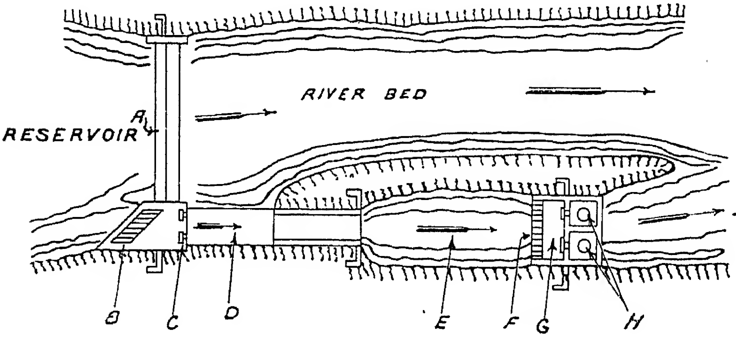


Fig. 179.

Again, the velocity in the tail race in very low falls should not exceed 2 feet per second, or at most 3 feet per second with falls not less than 5 feet, as too high a velocity causes eddy currents and destroys the suction action through the admission of air.

Where a suction pipe is fixed it should be arranged to taper from the turbine runner downwards.

As previously mentioned, horizontal or vertical turbines may be used at low-fall developments according to local conditions, and examples of each class of development will be briefly described.

Horizontal Turbine Installations.—An arrangement of horizontal turbines for a low-fall hydro-electric power house is

shown in Fig. 180, the wheels being mounted in pairs within a steel casing and upon a common shaft. The water is delivered to the centre of the casing and discharges right and left to the draught tube, thus neutralising thrust on the end bearings and, owing to the direction of the streams, avoiding eddies in the water and loss of efficiency.

The arrangement illustrated allows accessibility to the turbine shaft for the direct coupling of the electrical generator.

Korsnäs Power House.—Horizontal turbines have been installed at falls having a head as low as 6 feet, as at the power station at Korsnäs in Sweden, shown in Fig. 181. At this installation there are four pairs of turbines—eight runners in

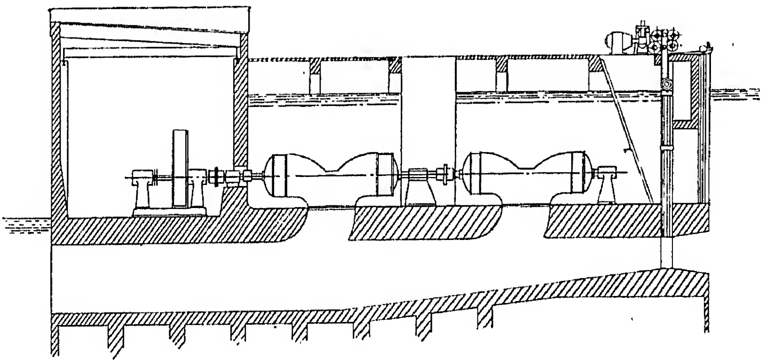


FIG. 180.

all—on one shaft which runs at a speed of 107 R.P.M. and develops 420 H.P. The automatic governors are fixed on the floor above the generator room, as shown in the figure.

Vertical Turbine Installations.—Vertical turbines take up less room than the horizontal types and have other advantages, as previously mentioned. They have been widely used for small and medium-sized powers with very low heads, two or more runners being often mounted on one shaft for the purpose of securing a higher speed. In America, there has been a notable development during recent years of very large powers utilizing high capacity single runner vertical turbines under heads ranging from 30 to 60 feet.

Avesta Lillfors Power House.—A typical lay-out of vertical

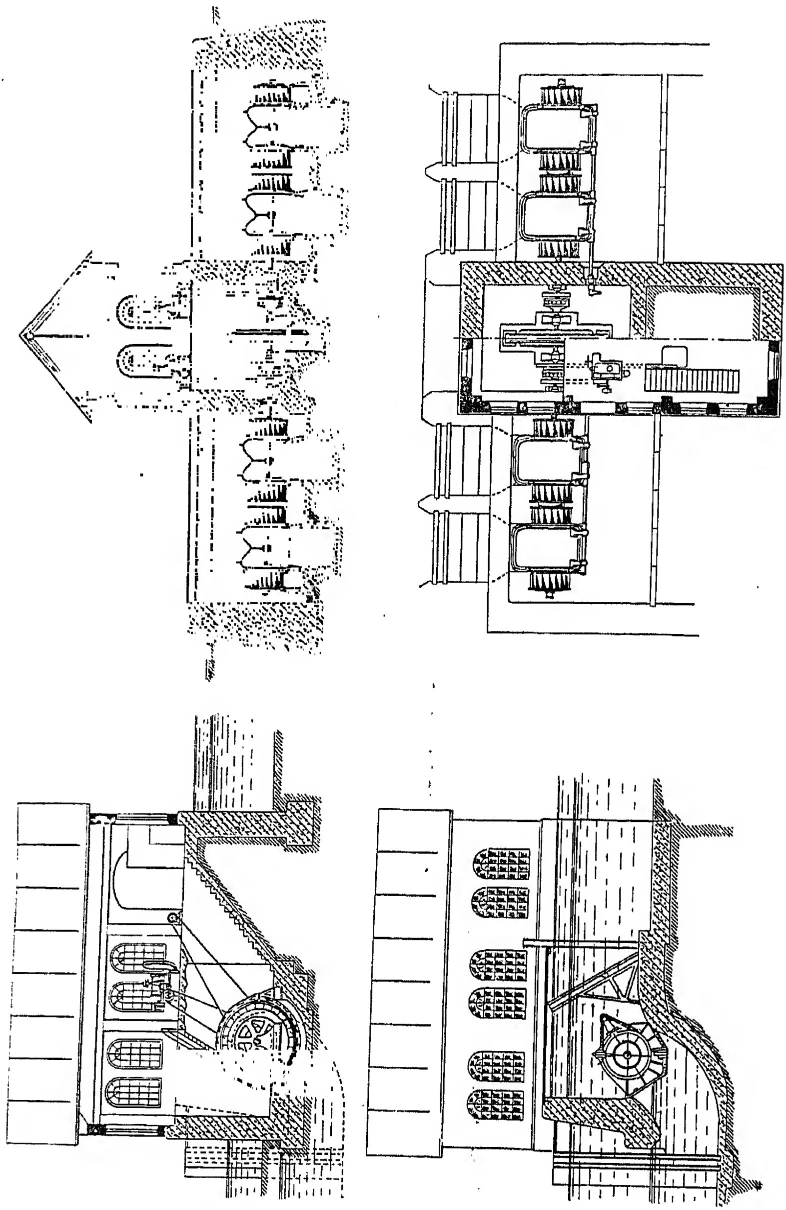


FIG. 181.

twin turbines for a nett head of 10 feet is shown in Fig. 182 which illustrates the power house at Avesta Lillfors, Sweden. The units develop 680 B.H.P. at a speed of 107 R.P.M., and have an efficiency of 82·5 per cent. The upper wheel dis-

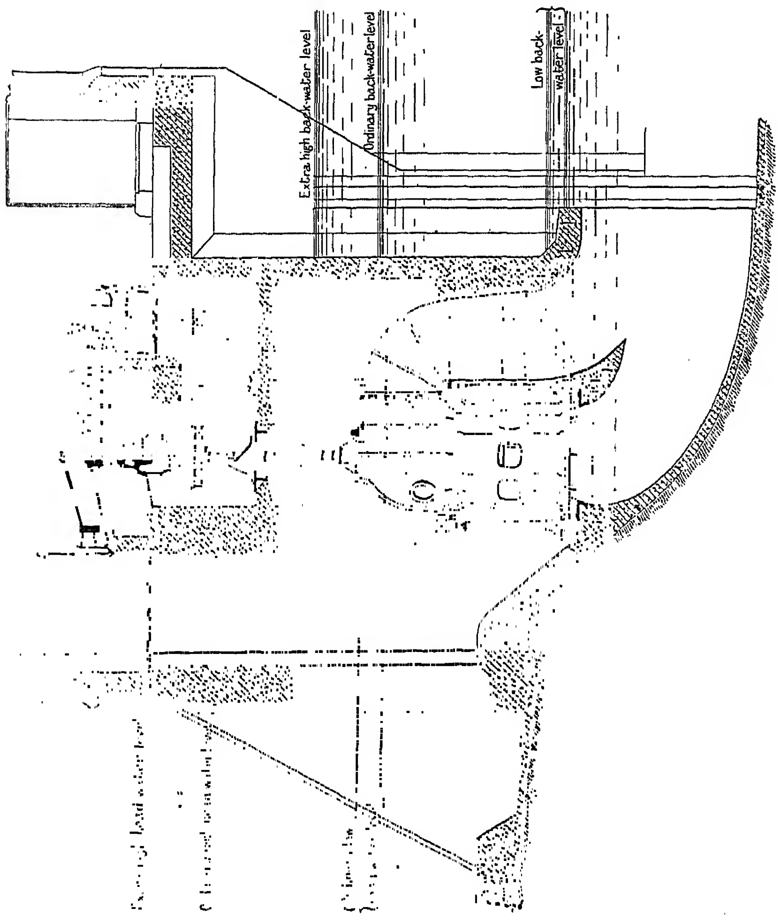


FIG. 182.

charges upwards through a draught tube, and the lower wheel discharges downwards, thus not requiring one.

An examination of Fig. 182 will show that the tail race level is sometimes higher than the upper end of the discharge casing of the upper turbine. At other times during periods of low

backwater the water is only level with the bottom of the lower wheel, and the draught tube of the upper turbine then comes into use. This is a good case for the adoption of vertical shaft turbines. If a horizontal type had been installed, the tail race level would have at times been considerably higher than the generator room floor level, which would have required the generators to have been placed in a water-tight sunken chamber.

Chester Power House.—The hydro-electric power house of the Corporation of Chester, England, used for supplementing the output of the municipal steam power station, affords another example of a typical low-fall development with vertical turbines. In this case an existing weir in the tidal portion of the River Dee was made use of, and careful consideration had to be given, when designing the installation, to the effect of the tides upon the operation of the turbines and also to the wide variations in the flow of the river. The three single-runner vertical turbines installed were specially designed for heads varying from 1 foot to 9 feet. The two larger units each deal with 30,000 cubic feet of water per minute and the smaller with 22,000 cubic feet, under a head of 9 feet, the corresponding outputs being 415 and 305 B.H.P., and the speeds 50 and 55 R.P.M. The two largest units are geared to generators each having an output of 225 K.W. at speeds varying between 143 and 285 R.P.M., and the smaller unit is geared to a generator having an output of 185 K.W. at any speed between 167 and 300 R.P.M.

Medium-Fall Water Powers.—A brief account may be given of a few hydro-electric power houses with heads ranging from say 60 to 200 feet in order to illustrate the nature of the problems that may confront the designer and of the works requiring to be constructed. The examples dealt with relate to installations comprising horizontal turbines, and for information concerning recent developments utilizing high capacity vertical units the reader should consult the paper by Mr. E. M. Bergstrom read before the Institution of Mechanical Engineers, England, in 1920.

Gullspång Power House. — The power house erected at Gullspång, Sweden, utilizes a fall of 65 feet, and a section through the power house showing the forebay, ice racks, sluices,

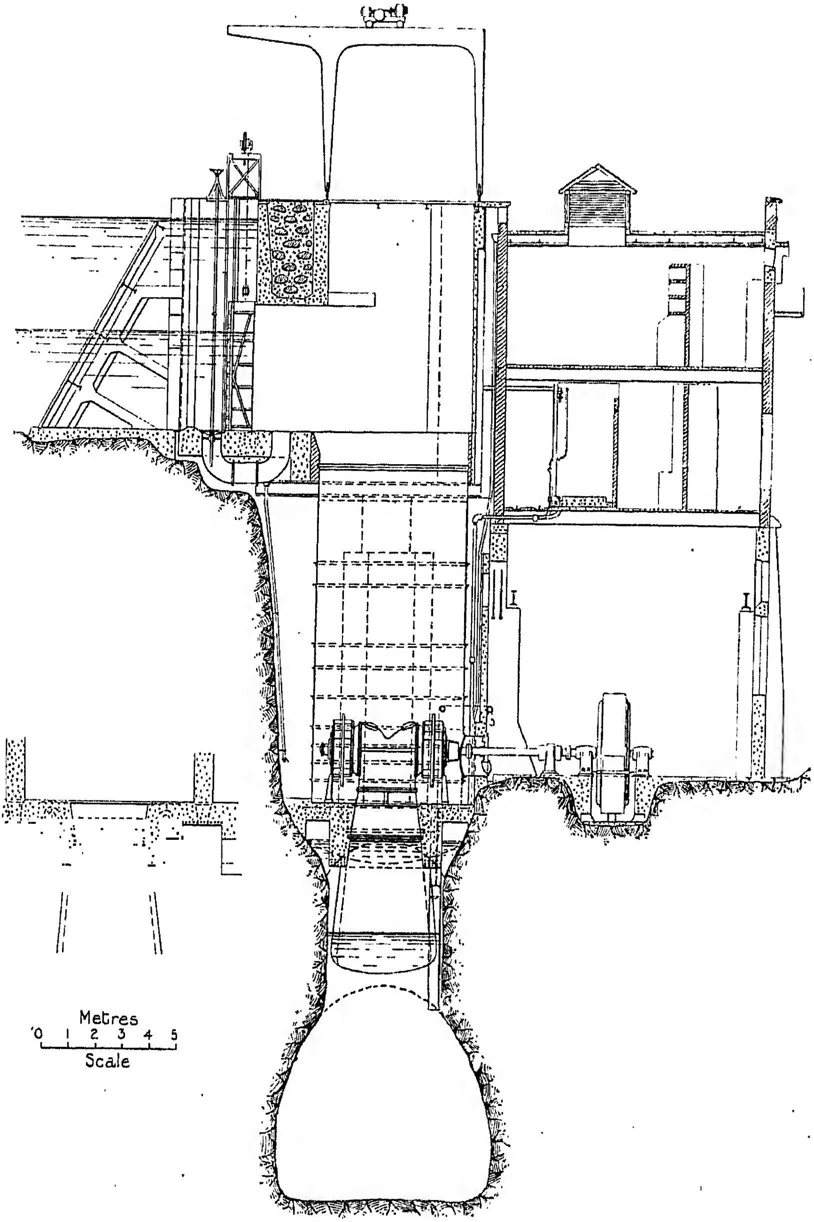


Fig. 188.

flume, turbines, draught tube, and tail race is given in Fig. 183. A description has already been given (p. 463) of the construction of the dam at this site, these works involving the temporary diversion of the river by means of a tunnel 60 yards long by 30 feet in diameter which had to be blasted in the neighbouring gneiss.

The twin horizontal turbines each have an output of 5000 H.P. (i.e. 2500 H.P. per runner) at a normal speed of 250 R.P.M., and together with their cement-coated supply pipes and draught tubes, are supported on a floor of heavy steel girders and reinforced concrete. The runners carry boiler plate buckets

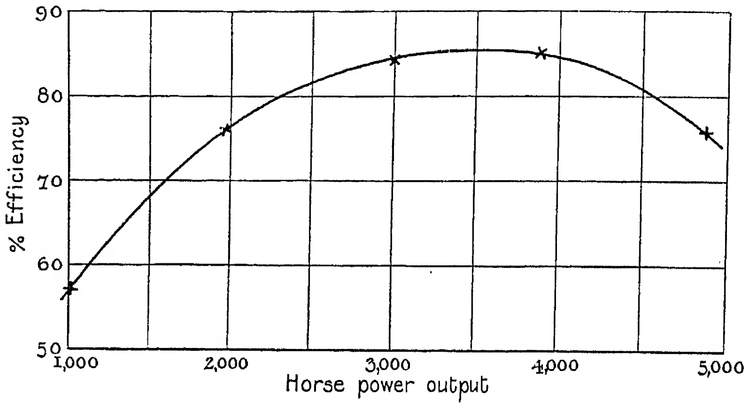


Fig. 184.

formed to the correct shape and cast into an iron hub and ring. A bucket which is smooth and even, thus minimizing skin friction, and also of strong construction is thereby obtained and is preferable to a cast bucket which may be damaged by stones, ice, etc., coming over with the water. The chutes leading the water into the wheel are movable on pivots for the purpose of varying the openings between them and effecting the regulation of the flow in a way which ensures the projection of the water on to the buckets at the correct angle, this improving the efficiency at light loads. The efficiency curve of one of the machines is shown in Fig. 184.

The turbines are placed in open vertical flumes built of boiler plate, each 43 feet long by 18 feet diameter, two 5000 H.P. sets

being in each flume. Each flume was well greased before the concrete was formed around it so as to allow for expansion, and has its own forebay, ice rack, and head gate. The latter are 18 feet wide by 15 feet high, and consist of semi-cylinders of iron plates stayed with horizontal struts and faced with oak sliding surfaces. The gates are too large to operate against the water pressure, and are arranged with bye-passes which fill the forebays and equalize the pressure. The turbine speed regulation is governed by automatic hydraulic regulators operating directly on the movable chutes referred to above. The governor is driven from the turbine shaft, and controls a small valve which admits water to one or the other end of a relay cylinder according as the speed rises or falls. The relay piston operates the movable chutes through a rack and segment. The tachograph records of these machines showed that the variation of speed was only $5\frac{1}{2}$ per cent. on the imposition of full load to the turbine running light, or on throwing off the full load, and 2 per cent. for variations amounting to half the rated load, there being absolutely no hunting effects.

Åtvidaberg Power House.—A medium-fall development of a different character is shown in Plate XX., which gives a plan and longitudinal section of the power house at Åtvidaberg, Sweden. The turbines in this case are supplied from a pressure pipe carried in a trench underneath the floor of the generator room, as shown in the figures, the pipe having skew branches to each turbine. The nett head is 66 feet, and there are three generator turbines each developing 200 H.P. at a normal speed of 500 R.P.M., and two exciter turbines each developing 15 B.H.P. at a speed of 1000 R.P.M. The turbine efficiencies obtained are 81·9 per cent. at full load, 82 per. cent. at three-quarter load, and 81·6 per cent. at half load.

Ontario Power House.—The Ontario power development at Niagara affords a good example of the class of civil engineering works involved in very large hydro-electric schemes, and the Author has extracted some of the salient features from a paper by P. N. Nunn read before the American Institute of Electrical Engineers in 1905. A map of the Niagara Falls showing the position of the power houses is given in Fig. 185.


ONTARIO POWER COMPANY'S INTAKE
ELECTRICAL DEVELOPMENT COMPANY
CANADIAN NIAGARA POWER COMPANY
HORSE
AMERICAN FALLS
COMPANY STATION
POWER HOUSE No. 2
POWER HOUSE No. 1
NIAGARA FALLS POWER COMPANY
A.E.B.

FIG. 185.

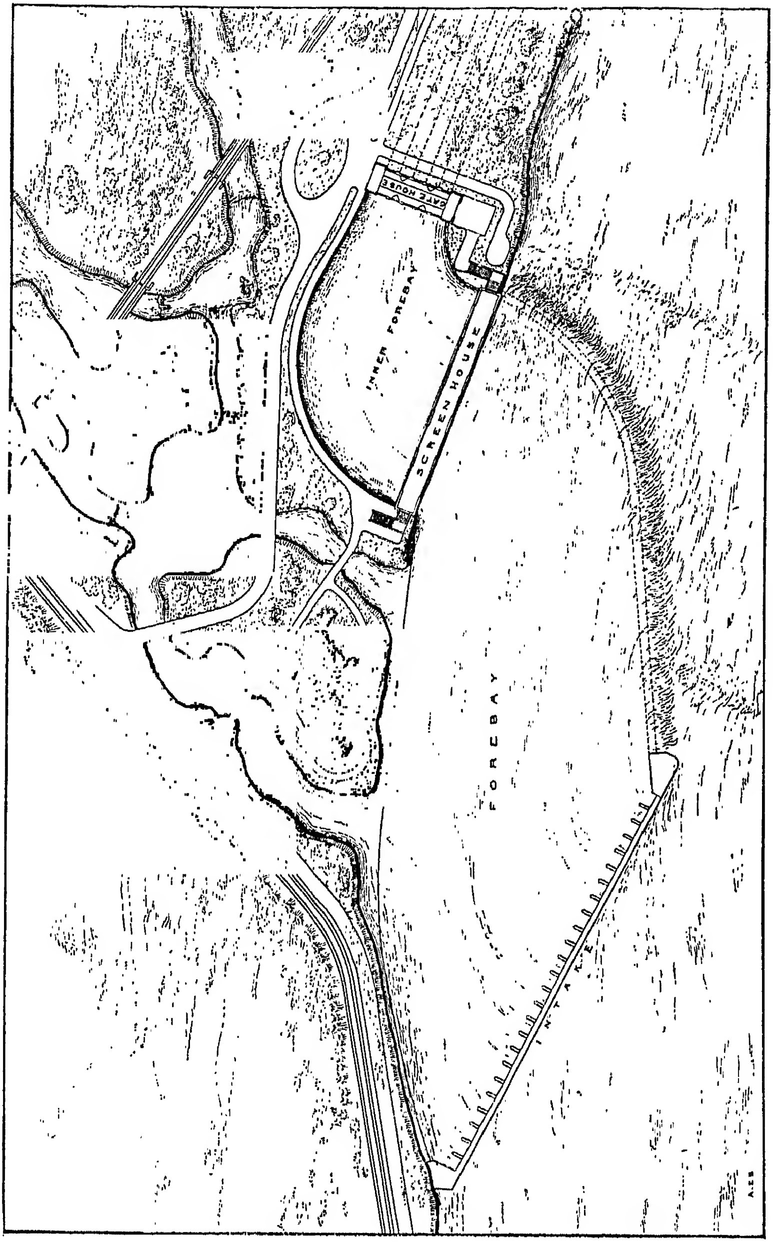


FIG. 186.

The intake works are located with special regard to the ice difficulties. Cake ice in enormous quantities is carried down from the lakes for weeks at a time, and a long tapering forebay, the entrance to which is protected by the main intake, terminates in a deep spillway, as shown in Fig. 186. On the river side the forebay is enclosed by a submerged wall. The other side is occupied partly by a screen house leading to the inner bay and to the head gates.

The intake, 600 feet long, is almost parallel with the current in the river, and a concrete curtain wall, as shown in Fig. 187, extends 9 feet into the water which is 15 feet deep at this point. Thus the gate openings beneath the curtain admit only deep

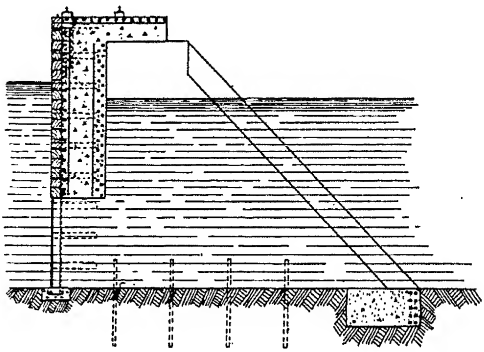


FIG. 187.

water, and this only at right angles to the swiftly flowing surface water, which carries off the pack ice to the rapids beyond.

This operation is repeated at the main screen, and a section through the screenhouse is shown in Fig. 188. This, again, lies parallel to the flow in the bay, and is so constructed that the front wall of the superstructure forms a curtain, admitting only deep water to the screens, excluding the surface water and ice which is carried away by the flow of the stream. An exterior view of the screenhouse, which is built in concrete, is shown in Fig. 189.

A section through the gatehouse, where the water is 30 feet deep, is shown in Fig. 190, and an exterior view of the building, also in concrete, is shown in Fig. 191.

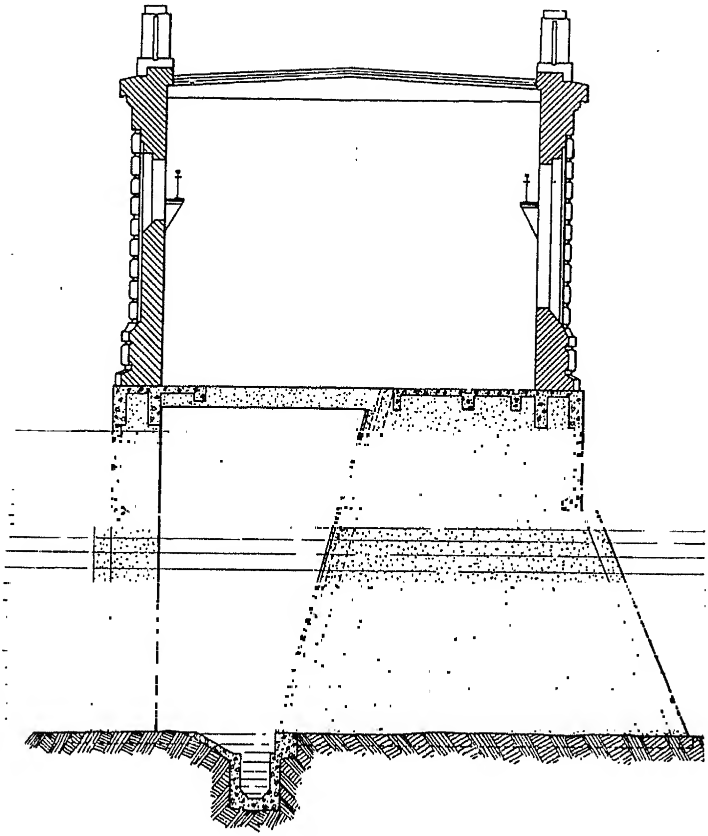


FIG. 188.

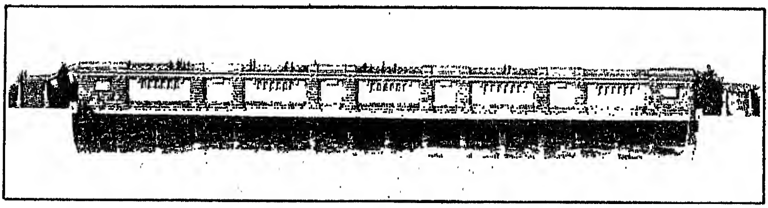


FIG. 189.

Both buildings are heated by steam supplied from an underground boiler plant located in the common abutment. It will be seen that the water has to pass in succession three steps, each excluding surface water and floating ice, and through two screens.

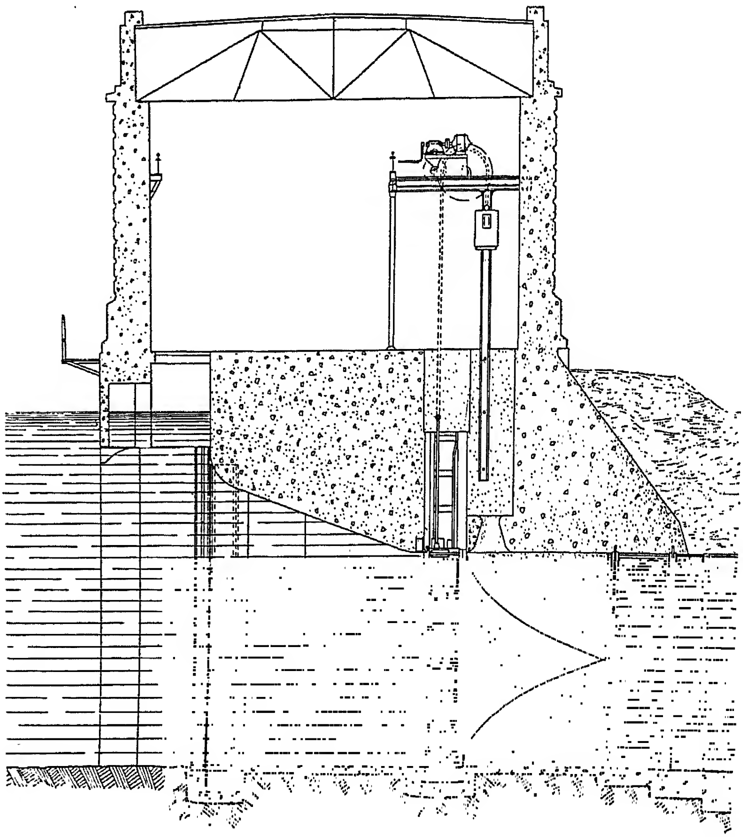


Fig. 190.

Electric cranes are provided for lifting the latter for cleaning and changing.

From the head gates, three steel and concrete tunnels, carrying 12,000 cubic feet per second, conduct the water to the top of the cliff above the power house. The main conduits have diameters of 18 and 20 feet and are of 0·5 inch riveted and

reinforced steel plate embedded in concrete. The velocity of flow is about 15 feet per second.

The conduit is provided at its end with a helical spillway, which is really an elevated end of the main, fitted with an adjustable weir and discharge tunnel. The object of this is to prevent water hammer in the event of a sudden loss of load.

Beneath the top of the cliff, and situated in a long, underground chamber, the arched roof of which supports the conduits, branches 9 feet in diameter pass from the conduit and carry the water through electrically operated gate-valves (con-

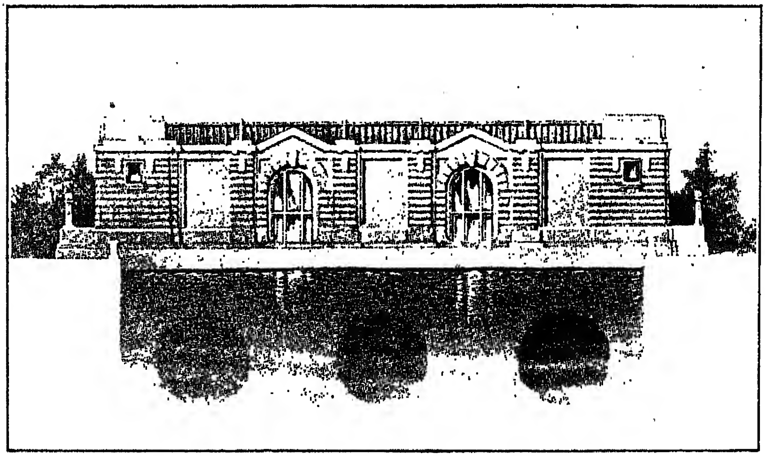


FIG. 191.

trolled from the power house) to the penstocks, each of which supplies water to its turbine with a velocity of 10 feet per second. Each penstock has a massive thrust anchorage in the power house foundations, two expansion joints, an automatic relief valve, and a stone catch discharging into the river.

Fig. 192 shows a section through the power house, and Fig. 193 gives a plan of the power house and also of the high-level distributing station.

The engine-room floor level is 26 feet above the mean water level, and the turbines and generators are arranged in single line. The space between them and the rear wall is occupied by

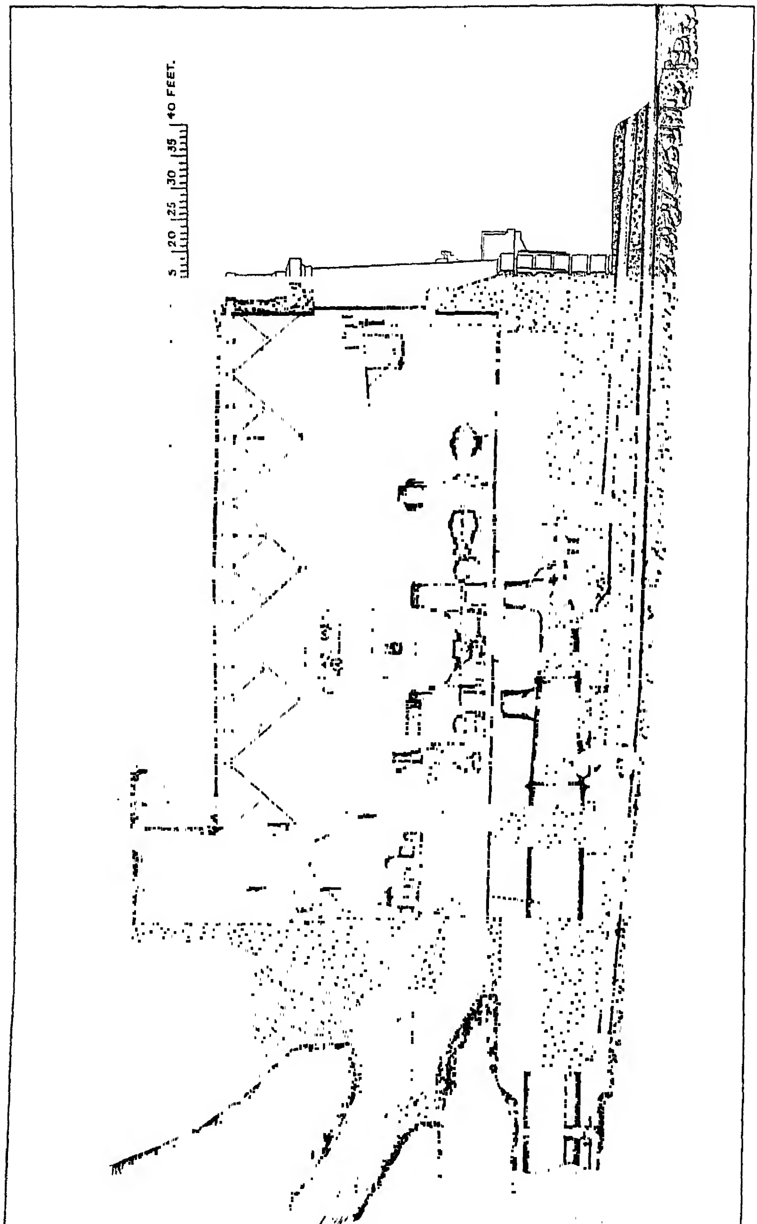


FIG. 192.

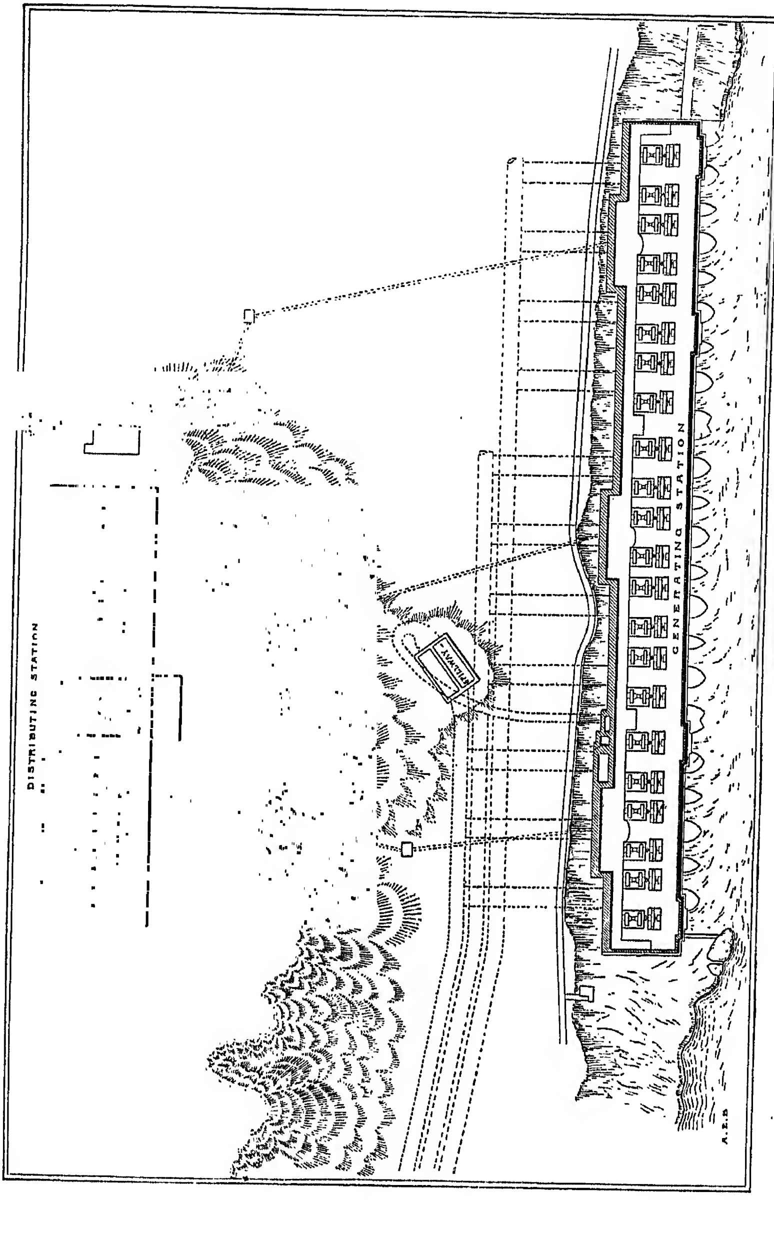


FIG. 193.

a gallery carrying the row of oil pressure governors, each over the end-bearing of its corresponding turbine. On this gallery the engineer has the motor-driven rheostats and the exciters, and a switchboard giving him electrical control of the penstock valves, and also control of the turbine speeds and excitation. He also has a clear view of all the machines.

Horizontal turbines are used so that all moving parts are in full view, and by the removal of a single ring the guides are exposed for cleaning and renewal. The balanced twin turbines are of the inward flow type with central discharge and with 78-inch cast-steel runners mounted on 24-inch shafts, each set developing 12,000 H.P. under a head of 175 feet, 20 feet of which is due to the 10-feet diameter draught tubes. The housings are of reinforced steel plate.

The bearings are self-oiling, fitted with a water-cooling system and with a pipe system for the changing of oil, and so arranged that in an emergency a forced lubricator can be utilized.

High-fall Water Powers.—Two high-fall power houses may now be described by way of example, one installation comprising vertical reaction turbines of large size and the other Pelton wheels.

Great Western Company's Power House, California.—At this power station, which is shown in section in Fig. 194, an available head of 450 feet is utilized.

In the river from which the supply is taken there is a cylindrical concrete intake tower built on a rock bottom, and designed with buttresses and guides for racks with openings at four levels provided with gates, as shown in Fig. 195. Cranes are provided to operate both screens and gates, the latter being operated electrically. Clean water is thus available, and is conveyed to a point above the power house by a tunnel 5000 yards in length and 220 square feet in cross-section with a gradient of 1 in 3000. The tunnel is lined with concrete 21 inches in thickness and is designed for a maximum pressure of 87 lb. per square inch. The steel pipe feeders from the tunnel to the turbines are constructed of steel plate varying from $\frac{1}{2}$ inch to 1 inch in thickness, with an inside diameter of 16 feet 9 inches

tapering to 6 feet. A surge pipe 9 feet in diameter and 300

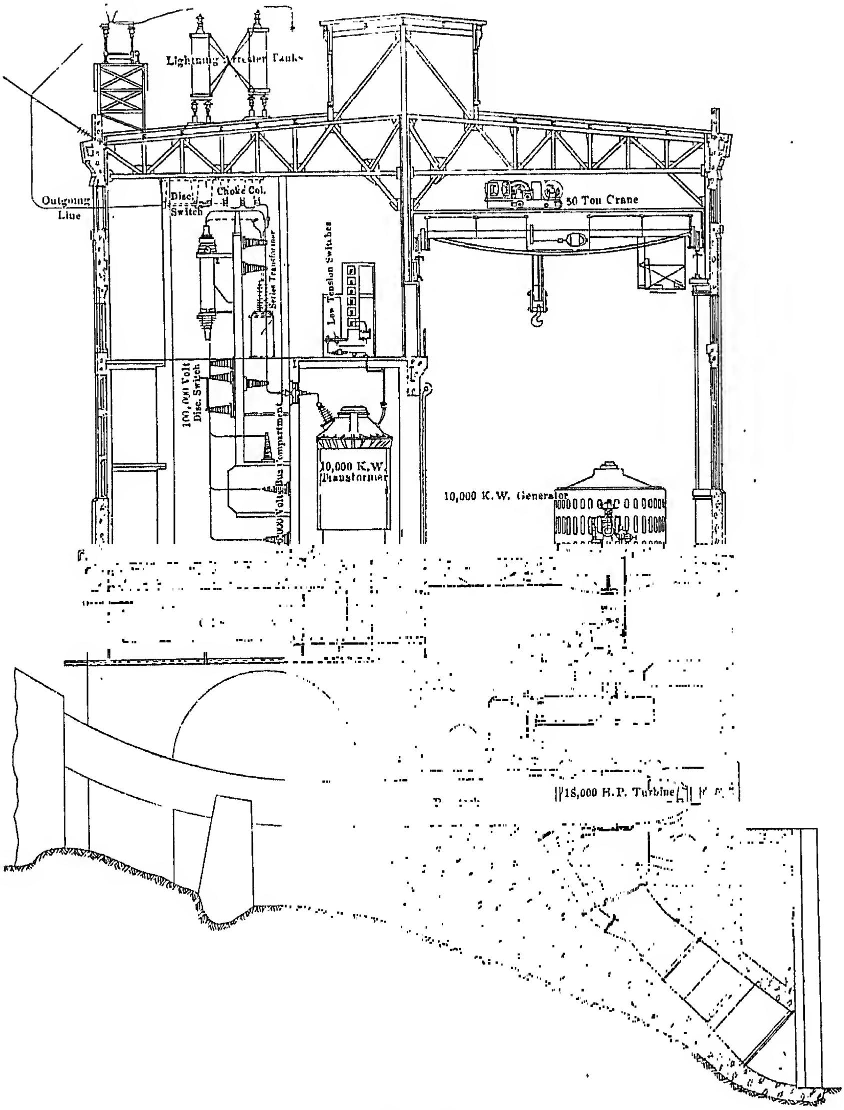


FIG. 194.

feet long is provided and empties into a spillway. The penstocks are 5 feet in diameter and 0·68 inch in thickness with air

and butterfly valves at the top of the penstock. The butterfly valves are operated by hand and the gate valves by motors controlled, as usual, from the switchboard.

The power house is a steel frame building 71 feet wide by 184 feet long with concrete panels, and is shown in Fig. 194. It is erected on massive concrete foundations and arranged with basements to take the turbines, step bearings, pumps, and accumulators. A 50-ton electric crane is fixed in the generator room. The power house contains four 18,000-H.P. reaction

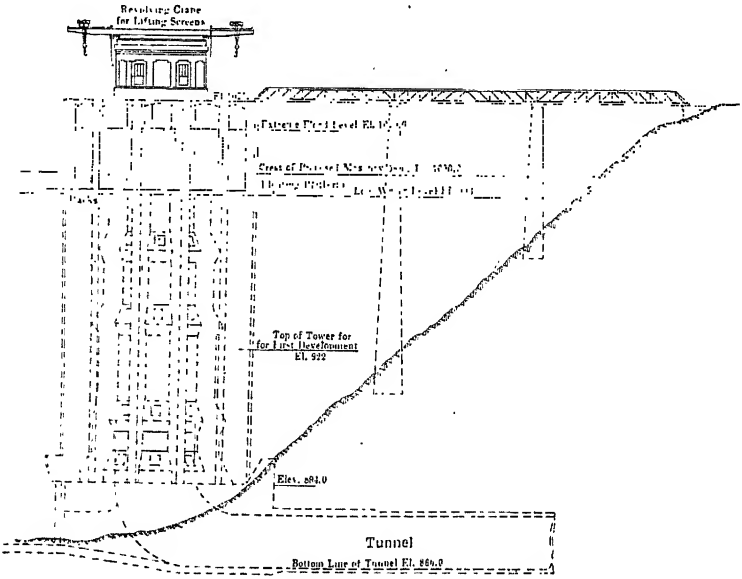
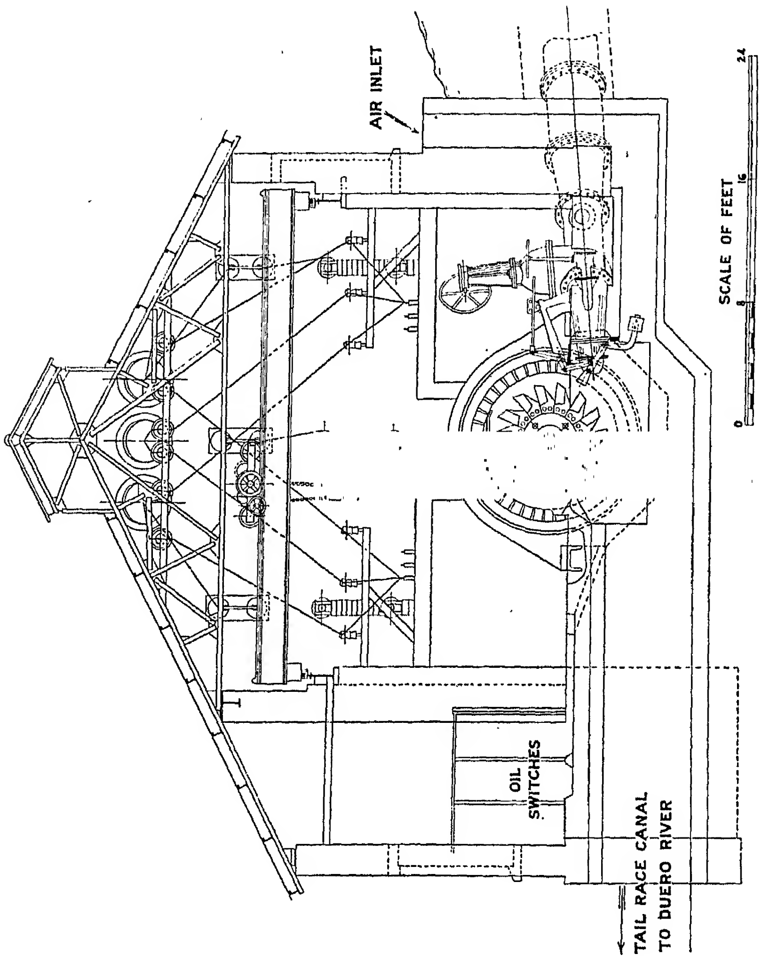


FIG. 195.

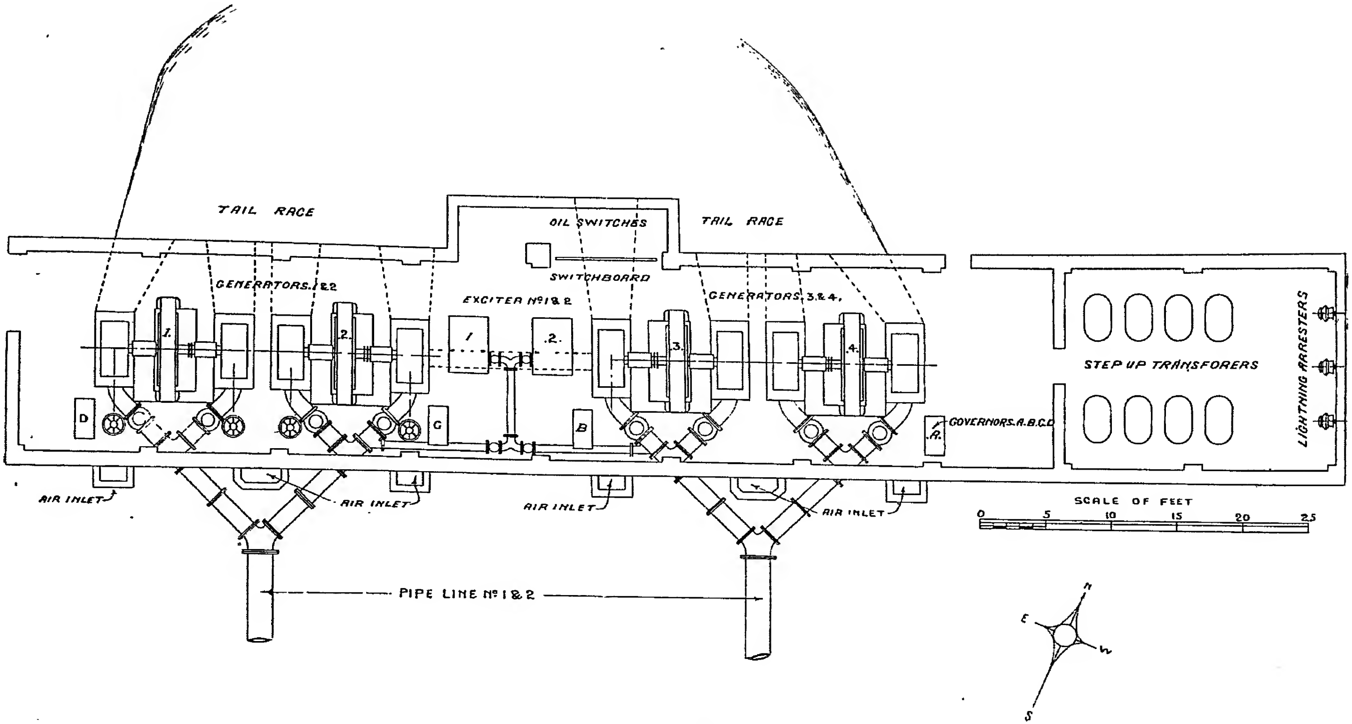
turbines of the vertical inward-flow type and two 500 H.P. impulse wheels, coupled respectively to 10,000 K.V.A. 3-phase generators (11,000 volts, 60 cycles), and to 250 K.W., 250 volt direct-current generators. The 18,000 H.P. reaction turbines have a speed of 400 R.P.M., and are constructed with cast steel casings, bronze runners, and 9-inch vanes of cast steel. The thrust bearings carry a total weight of 65 tons and are supplied with oil at a pressure of 250 lb. per square inch. The guaranteed over-all efficiencies were 80 per cent. at full load, 82 per cent. at three-quarter load, and 76 per cent. at half load.

Guanajuato Power House, Mexico.—This is another typical hydro-electric power house, whence energy is transmitted a distance of 101 miles at a pressure of 60 kilovolts. A cross-section of the power house is shown in Fig. 196 and a plan in Fig. 197.



Elevation.
FIG. 196.

The curved masonry dam for directing the water to the head race is built from local erupted rock, partly laid in lime mortar and faced with masonry set in cement, and is 90 yards long. Water is admitted through four head gates with a maximum


TAIL RACE
TAIL RACE
OIL SWITCHES
SWITCHBOARD
GENERATORS 1&2
GENERATORS 3&4
EXCITER Nº 1&2
1.
2.
3.
4.
D
G
B
A
GOVERNORS A.B.C.D
STEP UP TRANSFORERS
LIGHTNING ARRESTERS
AIR INLET
AIR INLET
AIR INLET
AIR INLET
AIR INLET
PIPE LINE Nº 1&2
SCALE OF FEET
0
5
10
15
20
25
N
E
W
S

Plan.
Fig. 197.

flow of 2·6 feet per second. The head race or canal is 7300 yards in length, 13 feet wide at the bottom, and 7 feet deep. The side slopes are: 1 : 1 in soft earth, 1 : 2 in hard rock, and 1 : 5 where masonry lined. The grade is a uniform 1 : 2500, and the capacity 280 cubic feet per second. A spillway and a settling basin are provided, as well as a small storage reservoir.

The pipe line is 1100 yards long, and the diameter and thickness of the pipe vary respectively from 69 inches and $\frac{5}{16}$ inch to 57 inches and $\frac{5}{8}$ inch. The steel was specified to have a tensile strength of 24 to 28 tons per square inch, with an elastic limit of one half these figures, and a minimum elongation of 25 per cent. The longitudinal seams are double riveted, and the circular seams single riveted.

The power house is 200 feet long by 32 feet wide and is built of local volcanic stone. The roof is of galvanized iron on steel principals and is lined with an anti-condensation material. The general lay-out of the Pelton wheels, generators, and other plant is shown in the plan view in Fig. 197. The power house is fitted with two ten-ton cranes.

Capital and Working Costs.—The capital cost of a hydro-electric development depends upon numerous factors; for example the topography and geology of a district which govern the nature and extent of the civil engineering works necessary; the value of the water power rights and of the amenities or interests which may be affected; the facilities for access and transport of materials and plant to the site; the availability or otherwise of local labour, and so forth. The relative influence of the different factors will vary from site to site, with the result that the capital costs of hydro-electric schemes of comparable size, whether in different countries or even in the same country, may exhibit wide differences. Similar considerations apply as regards the working costs of hydro-electric power houses, for in the generality of cases these expenses are mainly composed of capital charges.

Nevertheless, it may be informative to deal on broad lines with the results of ascertained practice, and the Author will therefore quote some of the data contained in a valuable statistical report issued by the Swedish Government in 1919 and

entitled "Sveriges Monterade Vattenkraft" (developed water power in Sweden). This report deals in great detail with the financial aspects of water power development in that country, and includes an analysis of the capital and running costs of a large number of undertakings of all sizes. The diagrams and tables given below are taken from the report, additional columns having been incorporated in the tables to show the equivalent costs in English money. The pre-war value of the Kroner, namely 13·5 pence, has been used in making the conversions.

Fig. 198 illustrates in graphical form the average constructional cost of Swedish water power schemes of different sizes, exclusive of the cost of the water power rights. Separate curves are given for hydro-electric undertakings, and for works at which the power developed is utilized direct or else for mixed purposes.

It will be seen that the average constructional costs per K.W. or per H.P. installed do not vary to any great extent for powers ranging from 4000 K.W. upwards, although exhibiting a tendency to decrease with increasing size. On the other hand, the average costs per K.W. installed increase rapidly for the small powers below 2000 K.W.

Table No. CXXIII. (p. 498) sets out the average capital costs (exclusive of the cost of water regulation) for a large number of developments of different classes and sizes. The constructional costs are divided between civil engineering works and machinery. In the case of hydro-electric undertakings, these items represent, on an average, about 74 per cent. and 26 per cent. respectively of the constructional costs. As would be expected, the percentage expenditure upon machinery increases as the size of the installation diminishes. Further analyses given in the Swedish report show that the power house itself represents, on an average, about 24·5 per cent. of the cost of the civil engineering works, while the electrical equipment accounts for about 67 per cent. of the machinery costs, the turbines accounting for the remaining 33 per cent. For a typical hydro-electric scheme, the construction costs under Swedish conditions would therefore be divided approximately as follows: civil engineering works other than power house 56 per cent. of the

total; power house 18 per cent.; electrical equipment 17·5 per cent.; turbines 8·5 per cent.

Fig. 199 shows the average working costs for hydro-electric

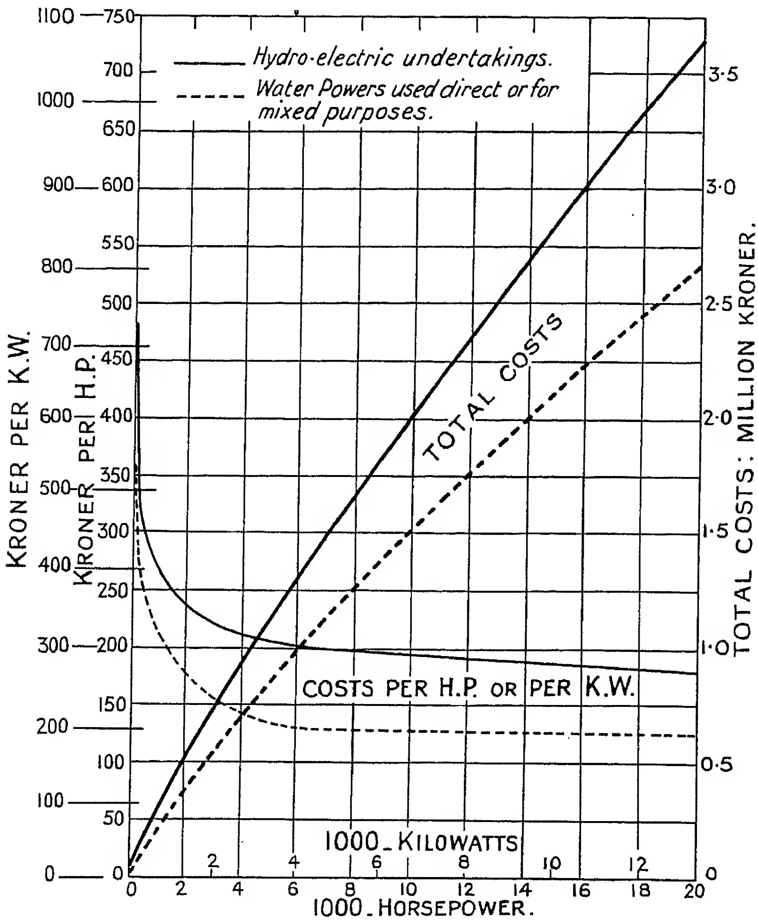


FIG. 198.

undertakings of different sizes, exclusive of interest and depreciation. One curve indicates the annual working costs in thousands of Kroner for power houses having an installed capacity up to 16,000 K.W., and the other curves show the annual costs per

TABLE CXXIII.

CAPITAL COSTS OF SWEDISH WATER POWER INSTALLATIONS.

(Showing Expenditure on Construction Work and Machinery.)

Class of installation and sizes.	Number of Installations.	Installed capacity. Turbine H.P.	Average capital costs per H.P. installed. Total (exclusive of water regulation). Kroner.	£.	Civil engineering works. Kroner.	£.	Per cent. of total.	Machinery. Kroner.	£.	Per cent. of total.
Hydro-electric undertakings:—										
Up to 200 H.P.	55	5,896	386	21·72	241	13·56	62·4	145	8·16	37·6
200 ,, 499 ,,	43	13,958	309	17·38	192	10·80	62·3	117	6·58	37·7
500 ,, 999 ,,	39	25,439	274	15·41	180	10·12	65·6	94	5·29	34·4
1,000 ,, 4,999 ,,	58	126,286	224	12·60	157	8·83	69·9	67	3·77	30·1
5,000 ,, 9,999 ,,	9	59,000	210	11·81	157	8·83	74·9	53	2·98	25·1
10,000 ,, 19,999 ,,	4	51,300	187	10·52	152	8·55	81·4	35	1·97	18·6
20,000 H.P. and over	7	305,825	150	8·44	115	6·53	77·0	34	1·91	23·0
Totals and averages	215	587,704	187	10·52	137	7·72	73·8	49	2·75	26·3
Works using water power direct or for mixed purposes:—										
Up to 200 H.P.	25	3,315	282	15·87	171	9·62	60·5	111	6·25	39·5
200 ,, 499 ,,	23	7,418	259	14·57	161	9·06	62·2	98	5·51	37·8
500 ,, 999 ,,	11	8,006	258	14·52	137	7·71	53·1	121	6·81	46·9
1,000 ,, 4,999 ,,	14	21,153	228	12·83	124	6·98	54·3	104	5·85	45 7
5,000 ,, 9,999 ,,	3	21,090	144	8·10	110	6·19	76·7	34	1·91	23·3
10,000 ,, 19,999 ,,	—	—	—	—	—	—	—	—	—	—
20,000 H.P. and over	1	24,360	121	6·81	103	5·80	84·9	18	1·01	15·1
Totals and averages	77	85,342	185	10·40	121	6·81	65·5	64	3·59	34·5
Grand totals and averages	292	673,046	186	10·46	135	7·60	72·7	51	2·86	27·3

H.P. (or K.W.) installed in relation to the size of the undertaking. The curve for "various costs" relates to items such as oil and stores, repairs and maintenance, rent, rates, and taxes, insurance, etc. The curves are based on costs prevailing during

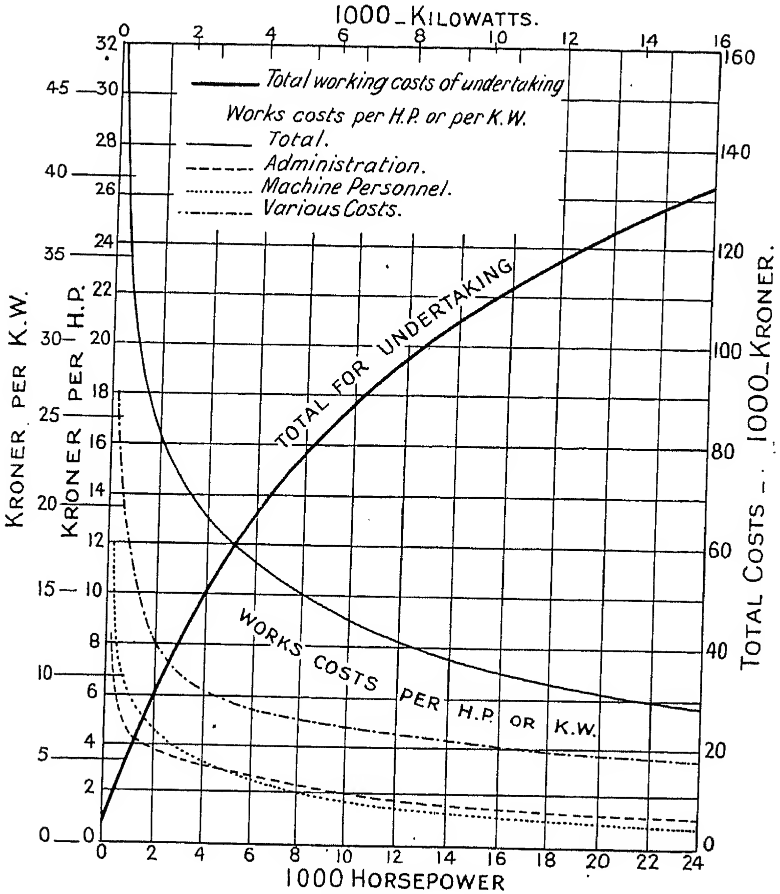


FIG. 199.

the year 1916 and thereabouts, and the general rise in prices caused by the war had already begun to be in evidence. No attempt was made in the report to bring the figures into line with the conditions prevailing at the date of their publication.

TABLE CXXIV.

SELECTED SWEDISH HYDRO-ELECTRIC UNDERTAKINGS.

(Data *re* Sizes, Output, and Capital Cost.)

Class of installation and sizes.	Number of Undertakings.	Installed capacity in K.W.		Output of electrical energy (1916 or nearest year of record).				Average capital costs per K.W. of total plant installed.			
		Water power plant.	Total, inclusive of reserve plant.	From water power plant.		From total installed plant.		Excluding cost of water power rights.		Total, including cost of water power rights.	
				K.W.H.	Effective working hours per annum.	K.W.H.	Effective working hours per annum.	Kroner.	£.	Kroner.	£.
State undertakings	3	138,851	138,851	522,368,000	3762	522,368,000	3762	331	18·6	485	27·3
Communal undertakings											
(a) For general distribution	11	8,478	11,565	21,756 000	2566	22,127,000	1913	688	38·7	769	43·2
(b) For industrial distribution	3	11,017	11,617	53,901,000	4892	54,873,000	4723	352	19·8	394	22·2
Private distribution undertakings:—											
Up to 1000 H.P.	11	3,487	3,687	8,969,000	2572	9,069,000	2459	598	33·6	783	44·1
1000 ,, 4999 ,,	10	19,920	23,062	71,762,000	3602	72,334 000	3136	477	26·8	582	32·8
5000 H.P. and over.	9	79,875	92,293	320,471,000	4012	326,888,000	3542	451	25·4	562	31·6
Industrial undertakings for supplying works requirements:—											
Up to 1000 H.P.	18	8,260	8,260	28,811,000	3488	28,811,000	3488	591	33·2	727	40·9
1000 ,, 4999 ,,	20	31,620	33,087	112,834,000	3568	114,565,000	3462	390	21·9	510	28·7
5000 H.P. and over	8	72,433	72,433	352,408,000	4865	352,408,000	4865	340	19·1	413	23·2
Totals and averages	93	373,941	394,855	1,493,280,000	3993	1,503,443,000	3807	393	22·1	511	28·7

Table No. CXXIV. gives particulars of ninety-three hydro-electric undertakings, comprising 119 installations, utilized for different purposes. It should be noted that the reserve plant at a number of the stations consists of steam or oil-driven engines. The table sets out the installed capacity of the various groups of undertakings, the corresponding output of electrical energy

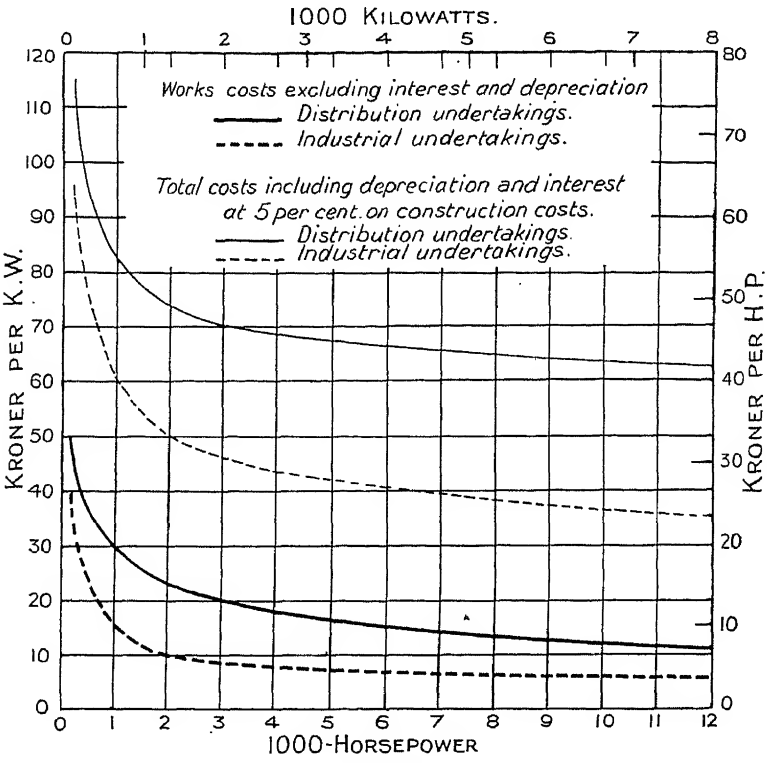


FIG. 200.

(in the calendar year 1916 or the nearest year of record), the average effective working hours corresponding to the output returned, and the average capital costs per K.W. of total plant installed.

The average working costs are set out graphically in Fig. 200 on a basis similar to that in Fig. 199, namely, Kroner per annum per K.W. (or H.P.) of installed plant for undertakings

up to a capacity of 8000 K.W. It will be seen that the annual working costs per unit of installed plant show a steady diminution as the size of the undertaking increases from about 2000 K.W., while for smaller power houses the costs increase rapidly.

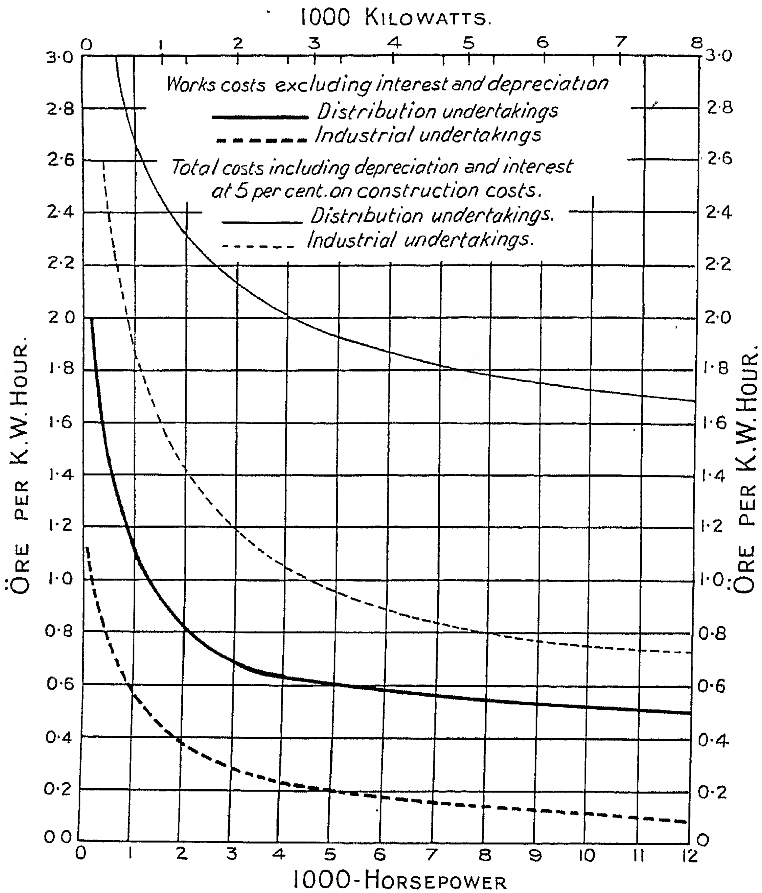


Fig. 201.

The large extent to which interest on capital and charges for depreciation enter into the total working costs is strikingly illustrated by the curves.

Fig. 201 sets out the corresponding working costs per K.W.H.

generated. At the pre-war rate of exchange the Swedish öre was equivalent to 0·135d.

In conclusion, the Author would point out that when considering the probable costs of a water power scheme under present-day conditions, great caution must be observed before applying any general deductions based upon typical costs in another country at a time when pre-war prices were only beginning to be affected.

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APPENDIX

ELECTRICITY REGULATIONS (GREAT BRITAIN)

MADE UNDER THE FACTORY AND WORKSHOP ACTS, 1901 AND 1907

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DEFINITIONS.

"PRESSURE" means the difference of electrical potential between any two conductors, or between a conductor and earth, as read by a hot wire or electrostatic volt-meter.

"Low Pressure" means a pressure in a system normally not exceeding 250 volts where the electrical energy is used.

"Medium Pressure" means a pressure in a system normally above 250 volts, but not exceeding 650 volts, where the electrical energy is used.

"High Pressure" means a pressure in a system normally above 650 volts, but not exceeding 3000 volts, where the electrical energy is used or supplied.

"Extra-high Pressure" means a pressure in a system normally exceeding 3000 volts, where the electrical energy is used or supplied.

"System" means an electrical system in which all the conductors and apparatus are electrically connected to a common source of electromotive force.

"Conductor" means an electrical conductor arranged to be electrically connected to a system.

"Apparatus" means electrical apparatus, and includes all apparatus, machines, and fittings in which conductors are used, or of which they form a part.

"Circuit" means an electrical circuit forming a system or branch of a system.

<table>
<tr><td>"Insulating stand" means a floor, platform, stand, or mat</td><td rowspan="4">of such size, quality, and construction according to the circumstances of the use thereof, that a person is thereby adequately protected from danger.</td></tr>
<tr><td>"Insulating screen" means a screen</td></tr>
<tr><td>"Insulating boots" means boots</td></tr>
<tr><td>"Insulating gloves" means gloves</td></tr>
</table>

"Covered with insulating material" means adequately covered with insulating material of such quality and thickness that there is no danger.

"Bare" means not covered with insulating material.

"Live" means electrically charged.

"Dead" means at, or about, zero potential, and disconnected from any live system.

"Earthed" means connected to the general mass of earth in such manner as will ensure at all times an immediate discharge of electrical energy without danger.

"Substation" means any premises, or that part of any premises, in which electrical energy is transformed or converted to or from pressure above medium pressure, except for the purpose of working instruments, relays, or similar auxiliary apparatus; if such premises or part of premises are large enough for a person to enter after the apparatus is in position.

"Switchboard" means the collection of switches or fuses, conductors, and other apparatus in connection therewith, used for the purpose of controlling the current or pressure in any system or part of a system.

"Switchboard passage-way" means any passage-way or compartment large enough for a person to enter, and used in connection with a switchboard when live.

"Authorized person" means (*a*) the occupier, or (*b*) a contractor for the time being under contract with the occupier, or (*c*) a person employed, appointed, or selected by the occupier, or by a contractor as aforesaid, to carry out certain duties incidental to the generation, transformation, distribution, or use of electrical energy, such occupier, contractor, or person being a person who is competent for the purposes of the regulation in which the term is used.

"Danger" means danger to health or danger to life or limb from shock, burn, or other injury to persons employed, or from fire attend-

ant upon the generation, transformation, distribution, or use of electrical energy.

"Public supply" means the supply of electrical energy (*a*) by any local authority, company or person authorized by Act of Parliament or Provisional Order confirmed by Parliament or by licence or Order of the Board of Trade to give a supply of electrical energy; or (*b*) otherwise under Board of Trade regulations.

Exemption 1.

Nothing in Regulations 2, 3, 4, 7, 9, 10, 11, 15, 16, 17, 21, 22, 23, 24, 25, 26, 28, 29, 30, and 31 shall apply, unless on account of special circumstances the Secretary of State shall give notice to the occupier that this exemption does not apply—

(*a*) To any system in which the pressure does not exceed low pressure direct or 125 volts alternating;

(*b*) In any public supply generating station, to any system in which the pressure between it and earth does not exceed low pressure;

(*c*) In any above-ground substation for public supply, to any system not exceeding low pressure.

Exemption 2.

Nothing in these Regulations shall apply to any service lines or apparatus on the supply side of the consumer's terminals, or to any chamber containing such service lines or apparatus, where the supply is given from outside under Board of Trade regulations; provided always that no live metal is exposed so that it may be touched.

Exemption 3.

If the occupier can show, with regard to any requirement of these Regulations, that the special conditions in his premises are such as adequately to prevent danger, that requirement shall be deemed to be satisfied; and the Secretary of State may by Order direct that any class of special conditions defined in the Order shall be deemed for the purposes of all or any of the requirements of these Regulations adequately to prevent danger, and may revoke such Order.

(Under this exemption the Secretary of State has made the following Order, § dated 28th July, 1909:—

In pursuance of Exemption 3 of the above Regulations, I hereby direct that in rooms, other than electrical stations, in which the following special conditions are observed, viz.:—

no electrical energy is used except at low pressure, nor for any purpose other than lighting by means of incandescent lamps; and

the floor is of wood or otherwise insulating; and

there is no machinery or other earthed metal with which a person handling any non-earthed lamp fittings or any portable lamp is liable to be in contact; and

no process rendering the floor wet is carried on; and

no live conductor is normally exposed so that it may be touched;

such conditions shall be deemed for all the purposes of the Regulations adequately to prevent danger.)

EXEMPTION 4.

Nothing in these Regulations shall apply to any process or apparatus used exclusively for electro-chemical or electro-thermal or testing or research purposes; provided such process be so worked and such apparatus so constructed and protected and such special precautions taken as may be necessary to prevent danger.

EXEMPTION 5.

The Secretary of State may, by Order, exempt from the operation of all or any of these Regulations any premises to which any special rules or regulations under any other Act as to the generation, transformation, distribution or use of electrical energy apply; and may revoke such Order.

(No Order has been made.)

EXEMPTION 6.

The Secretary of State may, if satisfied that safety is otherwise practically secured, or that exemption is necessary on the ground of emergency or special circumstances, grant such exemption by Order, subject to any conditions that may be prescribed therein; and may revoke such Order.

(No Order has been made.)

EXEMPTION 7.

Nothing in these Regulations shall apply to domestic factories or domestic workshops.

See Factory Act, 1901, s. 115.

Regulation 1.

All apparatus and conductors shall be sufficient in size and power for the work they are called upon to do, and so constructed, installed, protected, worked and maintained as to prevent danger so far as is reasonably practicable.

Regulation 2.

All conductors shall either be covered with insulating material, and further efficiently protected where necessary to prevent danger, or they shall be so placed and safeguarded as to prevent danger so far as is reasonably practicable.

Regulation 3.

Every switch, switch fuse, circuit-breaker, and isolating link shall be :—(*a*) so constructed, placed, or protected as to prevent danger; (*b*) so constructed and adjusted as accurately to make and to maintain good contact; (*c*) provided with an efficient handle or other means of working, insulated from the system, and so arranged that the hand cannot inadvertently touch live metal; (*d*) so constructed or arranged that it cannot accidentally fall or move into contact when left out of contact.

Regulation 4.

Every switch intended to be used for breaking a circuit and every circuit-breaker shall be so constructed that it cannot with proper care be left in partial contact. This applies to each pole of double-pole or multipole switches or circuit-breakers.

Every switch intended to be used for breaking a circuit and every circuit-breaker shall be so constructed that an arc cannot accidentally be maintained.

Regulation 5.

Every fuse, and every automatic circuit-breaker used instead thereof, shall be so constructed and arranged as effectively to interrupt the current before it so exceeds the working rate as to involve danger. It shall be of such construction or be so guarded or placed as to prevent danger from overheating, or from arcing or the scattering of hot metal or other substance when it comes into operation. Every fuse shall be either of such construction or so protected by a switch that the fusible metal may be readily renewed without danger.

REGULATION 6.

Every electrical joint and connection shall be of proper construction as regards conductivity, insulation, mechanical strength and protection.

REGULATION 7.

Efficient means suitably located shall be provided for cutting off all pressure from every part of a system, as may be necessary to prevent danger.

REGULATION 8.

Efficient means suitably located shall be provided for protecting from excess of current every part of a system, as may be necessary to prevent danger.

REGULATION 9.

Where one of the conductors of a system is connected to earth, no single-pole switch, other than a link for testing purposes or a switch for use in controlling a generator, shall be placed in such conductor or any branch thereof.

A switch, or automatic or other cut-out may, however, be placed in the connection between the conductor and earth at the generating station, for use in testing and emergencies only.

REGULATION 10.

Where one of the main conductors of a system is bare and uninsulated, such as a bare return of a concentric system, no switch, fuse, or circuit-breaker shall be placed in that conductor, or in any conductor connected thereto, and the said conductor shall be earthed.

Nevertheless, switches, fuses, or circuit-breakers may be used to break the connection with the generators or transformers supplying the power; provided that in no case of bare conductor the connection of the conductor with the earth is thereby broken.

REGULATION 11.

Every motor, converter and transformer shall be protected by efficient means suitably placed, and so connected that all pressure may thereby be cut off from the motor, converter or transformer as the case may be, and from all apparatus in connection therewith; provided, however, that where one point of the system is connected

to earth, there shall be no obligation to disconnect on that side of the system which is connected to earth.

Regulation 12.

Every electric motor shall be controlled by an efficient switch or switches for starting and stopping, so placed as to be easily worked by the person in charge of the motor.

In every place in which machines are being driven by any electric motor, there shall be means at hand for either switching off the motor or stopping the machines if necessary to prevent danger.

Regulation 13.

Every flexible wire for portable apparatus, for alternating currents or for pressures above 150 volts direct current, shall be connected to the system either by efficient permanent joints or connections, or by a properly constructed connector.

In all cases where the person handling portable apparatus or pendant lamps with switches, for alternating current or pressures above 150 volts direct current, would be liable to get a shock through a conducting floor or conducting work or otherwise, if the metal work of the portable apparatus became charged, the metal work must be efficiently earthed; and any flexible metallic covering of the conductors shall be itself efficiently earthed and shall not itself be the only earth connection for the metal of the apparatus. And a lampholder shall not be in metallic connection with the guard or other metal work of a portable lamp.

In such places and in any place where the pressure exceeds low pressure, the portable apparatus and its flexible wire shall be controlled by efficient means suitably located, and capable of cutting off the pressure, and the metal work shall be efficiently earthed independently of any flexible metallic cover of the conductors, and any such flexible covering shall itself be independently earthed.

Regulation 14.

The general arrangement of switchboards shall, so far as reasonably practicable, be such that—

(*a*) All parts which may have to be adjusted or handled are readily accessible.

(*b*) The course of every conductor may where necessary be readily traced.

(c) Conductors, not arranged for connection to the same system, are kept well apart, and can where necessary be readily distinguished.

(d) All bare conductors are so placed or protected as to prevent danger from accidental short circuit.

REGULATION 15.

Every switchboard having bare conductors normally so exposed that they may be touched, shall, if not located in an area or areas set apart for the purpose thereof, where necessary be suitably fenced or enclosed.

No person except an authorized person, or a person acting under his immediate supervision, shall for the purpose of carrying out his duties have access to any part of an area so set apart.

REGULATION 16.

All apparatus appertaining to a switchboard and requiring handling, shall so far as practicable be so placed or arranged as to be operated from the working platform of the switchboard, and all measuring instruments and indicators connected therewith shall, so far as practicable, be so placed as to be observed from the working platform. If such apparatus be worked or observed from any other place, adequate precautions shall be taken to prevent danger.

REGULATION 17.

At the working platform of every switchboard and in every switchboard passage-way, if there be bare conductors exposed or arranged to be exposed when live so that they may be touched, there shall be a clear and unobstructed passage of ample width and height, with a firm and even floor. Adequate means of access, free from danger, shall be provided for every switchboard passage-way.

The following provisions shall apply to all such switchboard working platforms and passage-ways constructed after January 1st, 1909, unless the bare conductors, whether overhead or at the sides of the passage-ways, are otherwise adequately protected against danger by divisions or screens or other suitable means :—

(a) Those constructed for low pressure and medium-pressure switchboards shall have a clear height of not less than 7 ft., and a clear width measured from bare conductor of not less than 3 ft.

(*b*) Those constructed for high-pressure and extra high-pressure switchboards, other than operating desks or panels working solely at low-pressure, shall have a clear height of not less than 8 ft., and a clear width measured from bare conductor of not less than 3 ft. 6 in.

(*c*) Bare conductors shall not be exposed on both sides of the switchboard passage-way unless either (i) the clear width of the passage is in the case of low-pressure and medium-pressure not less than 4 ft. 6 in., and in the case of high-pressure and extra high-pressure not less than 8 ft., in each case measured between bare conductors, or (ii) the conductors on one side are so guarded that they cannot be accidentally touched.

REGULATION 18.

In every switchboard for high-pressure or extra high-pressure :—

(*a*) Every high-pressure and extra high-pressure conductor within reach from the working platform or in any switchboard passage-way shall be so placed or protected as adequately to prevent danger.

(*b*) The metal cases of all instruments working at high-pressure or extra high-pressure shall be either earthed or completely enclosed with insulating covers.

(*c*) All metal handles of high-pressure and extra high-pressure switches, and, where necessary to prevent danger, all metal gear for working the switches, shall be earthed.

(*d*) When work has to be done on any switchboard, then, unless the switchboard be otherwise so arranged as to secure that the work may be carried out without danger, either (i) the switchboard shall be made dead, or (ii) if the said switchboard be so arranged that the conductors thereof can be made dead in sections, and so separated by permanent or removable divisions or screens from all adjoining sections of which the conductors are live, that work on any section may be carried out without danger, that section on which work has to be done shall be made dead.

REGULATION 19.

All parts of generators, motors, transformers, or other similar apparatus, at high-pressure or extra high-pressure, and within reach

from any position in which any person employed may require to be, shall be, so far as reasonably practicable, so protected as to prevent danger.

REGULATION 20.

Where a high-pressure or extra high-pressure supply is transformed for use at a lower pressure, or energy is transformed up to above low-pressure, suitable provision shall be made to guard against danger by reason of the lower-pressure system becoming accidentally charged above its normal pressure by leakage or contact from the higher-pressure system.

REGULATION 21.

Where necessary to prevent danger, adequate precautions shall be taken either by earthing or by other suitable means to prevent any metal other than the conductor from becoming electrically charged.

REGULATION 22.

Adequate precautions shall be taken to prevent any conductor or apparatus from being accidentally or inadvertently electrically charged when persons are working thereon.

REGULATION 23.

Where necessary adequately to prevent danger, insulating stands or screens shall be provided and kept permanently in position, and shall be maintained in sound condition.

REGULATION 24.

Portable insulating stands, screens, boots, gloves, or other suitable means shall be provided and used when necessary adequately to prevent danger, and shall be periodically examined by an authorized person.

REGULATION 25.

Adequate working space and means of access, free from danger, shall be provided for all apparatus that has to be worked or attended to by any person.

REGULATION 26.

All those parts of premises in which apparatus is placed shall be adequately lighted to prevent danger.

REGULATION 27.

All conductors and apparatus exposed to the weather, wet, corrosion, inflammable surroundings or explosive atmosphere, or used in any process or for any special purpose other than for lighting or power shall be so constructed or protected, and such special precautions shall be taken as may be necessary adequately to prevent danger in view of such exposure or use.

REGULATION 28.

No person except an authorized person or a competent person acting under his immediate supervision shall undertake any work where technical knowledge or experience is required in order adequately to avoid danger; and no person shall work alone in any case in which the Secretary of State directs that he shall not. No person except an authorized person, or a competent person over 21 years of age acting under his immediate supervision, shall undertake any repair, alteration, extension, cleaning, or such work where technical knowledge or experience is required in order to avoid danger, and no one shall do such work unaccompanied.

Where a contractor is employed, and the danger to be avoided is under his control, the contractor shall appoint the authorized person, but if the danger to be avoided is under the control of the occupier, the occupier shall appoint the authorized person.

REGULATION 29.

Instructions as to the treatment of persons suffering from electric shock shall be affixed in all premises where electrical energy is generated, transformed, or used above low-pressure; and in such premises, or classes of premises, in which electrical energy is generated, transformed or used at low-pressure, as the Secretary of State may direct.

REGULATION 30.

Every substation shall be substantially constructed, and shall be so arranged that no person other than an authorized person can obtain access thereto otherwise than by the proper entrance, or can interfere with the apparatus or conductors therein from outside, and shall be provided with efficient means of ventilation and be kept dry.

REGULATION 31.

Every substation shall be under the control of an authorized person, and none but an authorized person or a person acting under his

immediate supervision shall enter any part thereof where there may be danger.

Regulation 32.

Every underground substation not otherwise easily and safely accessible shall be provided with adequate means of access by a door or trap-door, with a staircase or ladder securely fixed and so placed that no live part of any switchboard or any bare conductor shall be within reach of a person thereon: Provided however that the means of access to such substation shall be by a doorway and staircase (*a*) if any person is regularly employed therein, otherwise than for inspection or cleaning, or (*b*) if the sub-station is not of ample dimensions and there is therein either moving machinery other than ventilating fans, or extra high pressure.

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